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Diurnal and interdiurnal variations of the measured heights of pressure surfaces

by
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1. Introduction

It is well known that there are systematic diurnal changes, which vary with the season and become increasingly important with height, in the measured heights of pressure surfaces. At 100 mb, the diurnal variations may be up to four times as great as the average 12 hr synoptic change, and together with the random errors of measurement they have the effect of completely masking the 12 hr contour height tendencies. The random errors are partially smoothed out in the process of chart construction. To eliminate diurnal effects, the analysts either have applied approximate seasonal corrections based on experience or have considered 24 hr height tendencies only. In order to provide a basis for strict comparison with each other of heights measured at different synoptic hours, the diurnal variations appropriate to all times of the year have been computed for Larkhill (51°12'N, 1°48'W), Lerwick (60°8'N, 1°11'W), Malta (35°50'N, 14°27'E) and Nicosia (35°9'N, 33°17'E).

There has been much speculation in the past as to whether the observed diurnal changes genuinely occur in the atmosphere. Recent work by Scrase (1) leads to the conclusion that the observed variations are largely false, being due to the effect of solar radiation on the thermometer element of the radiosonde rather than on the atmosphere itself. The synoptician, however, does not need to discriminate between the real and the spurious, provided that the variations occur, as the evidence suggests they do, on the scale of tides rather than on the synoptic scale. In either case he wishes to eliminate them in order to see clearly the synoptic changes.

2. The observed variations

Upper air charts are constructed for the hours, 0300 GMT, 0900 GMT, 1500 GMT and 2100 GMT and it is customary to think of the plotted observations as referring to those times. In fact, the British ascents normally start within a few minutes of 0200 GMT, 0800 GMT, etc., and they reach the 100 mb level about 40 minutes later. Lerwick ascents are exceptional in that they normally commence at 0145 GMT, 0745 GMT, etc. Conventionally the 6 hr variations will be referred to as the 0900-0300 GMT, etc. variations, even though the actual measurements are made during the hour or so preceding 0300 GMT, 0900 GMT, etc.

The diurnal changes have been computed for the standard pressure levels: 700 mb, 500 mb, 300 mb, 200 mb and 100 mb. For Larkhill and Lerwick four-year monthly mean 6 hr variations of contour height have been calculated for the years 1948-51, and five-year monthly mean 12 hr variations have been calculated for 1948-52. The Upper Air Climatology Branch of the Meteorological Office supplied monthly totals of contour heights, for individual hours, which had been obtained by Hollerith punched card methods. These totals were used in calculating the variations at levels up to 200 mb. The 100 mb monthly mean variations were computed from chosen occasions, when 100 mb heights were given

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in the Daily Aerological Record at the appropriate times t and t + 6 hr or t and t + 12 hr on the same day. Apparent anomalies in the Hollerith tables were checked by reference to individual observations given in the D.A.R. and to the Upper Air Forecaster's working charts.

Upper air observations are made regularly at Malta and Nicosia at 0300 GMT and at 1500 GMT, and for these stations, only the 12 hr 1500-0300 GMT variations could be computed. These refer to the years 1948-51 in the case of Malta and 1948-52 for Nicosia. Hollerith totals were again used except for those months when less than 25 observations were made at either hour. In these latter months recourse was made to the pairing procedure described above, the individual observations being obtained from the Overseas Supplement to the Daily Weather Report or from tabulations supplied by the Upper Air Climatology Branch.

All the computed 6 hr and 12 hr variations in the measured contour heights are contained in Tables 1 and 2.

3. Smoothed values

The observed diurnal variations contain "errors" due to real random synoptic variations and due to random errors of measurement of the contour heights. The effect of these "errors" can be seen in the graphs of the annual march of the diurnal variations contained in Figures 1 and 2. These graphs, while showing clear trends, are irregular, but there is no reason to suppose that an accurate graph of the seasonal variation would not be quite smooth. Where the curve forms are approximately sinusoidal, smoothing by fitting one or two harmonics is feasible. In some cases, however, the curves are not nearly sinusoidal and it is necessary to investigate the forms which the seasonal variations should take, theoretically.

F.J. Scrase has given a method (1) by which the radiation and lag errors of the Meteorological Office radio-sonde can be estimated. Scrase's calculations suggest that a large part of the observed diurnal variation of temperature can be accounted for in terms of radiation error. Integration of these estimated temperature errors can therefore be expected to provide a good indication of the form which the annual march of the observed diurnal variation of contour height takes.

Table V of M.R.P.836 (1) gives the calculated radiation errors at a number of heights for five solar altitudes from 10° to 90°. Interpolation within this table is not sufficiently accurate for present purposes, so the radiation errors have been calculated afresh from data given in Figure 2 and Table III of M.R.P.836, at one degree intervals over the range from -5° to 0° solar altitude, at five degree intervals from 0° to 40° solar altitude and at ten degree intervals from 40° to 70° solar altitude. It was necessary to extrapolate slightly certain of the curves given in Scrase's Figure 2 in order to obtain rates of absorption of radiation, by the thermometer element and its shield, at negative solar altitudes. Lag errors have been neglected since, according to Scrase (1), these are not appreciably affected by time of day at levels up to 100 mb. Radiation emitted (as distinct from reflected) from below the instrument has also been neglected since this, too, does not contribute an appreciable amount to the diurnal variation. Following Scrase, to allow for depletion of the sun's radiation by absorption and scattering before it reaches the sonde, use has been made of a diagram prepared by Vaisala (2), which gives the radiation intensity at the radio-sonde, as a percentage of the radiation intensity at the top of the atmosphere, in terms of the true solar altitude and the height of the instrument. This diagram takes into account the refraction of the sun's rays.

For the present work, diagrams have been prepared which enable the radiation temperature errors at any level up to 20 km to be read off for true solar altitudes between -5° and 70°. These are given as Figures 4(a) and (b). The true solar altitude at any place and at any time can be calculated from the formula $\sin A = \sin\delta \sin\phi + \cos\delta \cos\phi \cos\theta$ where A is the true solar

/altitude

altitude, δ is the sun's declination, ϕ is latitude and θ is the local hour angle. Curves giving the solar altitudes, (a) at the time the sonde leaves the surface and (b) at the time the sonde reaches 100 mb, have been calculated for each of the hours of observation at Larkhill, Lerwick, Malta and Nicosia. These are contained in Figure 5.

Interpolating where necessary, the temperature errors at all levels for the routine ascents were obtained using Figures 4 and 5. The consequent errors in the measured contour heights were then calculated using a convenient derivation of the hydrostatic equation,

$$\delta h' = 122{\cdot}8 \left(\log_{10} p_1/p_2 \right) \delta T$$

where δT is the temperature error in degrees Fahrenheit, p_2 and p_1 are pressures in mb at the top and the bottom of the layer whose thickness in feet is h'.

Increments in thickness of each 100 mb layer up to 300 mb and each 50 mb layer between 300 mb and 100 mb were calculated using the mean temperature error appropriate to each layer. The apparent diurnal variations of contour height which would result from these estimated radiation errors were computed for dates approximately at the beginning and centre of each month of the year. Figures 1 to 3 contain curves which show graphically the results of these calculations.

It is clear from Figures 1 and 2 that the diurnal variations computed from estimated radiation errors are mostly of similar magnitude to the variations computed from observations. Further, they illustrate the way in which a number of features of the "observed variation" curves can be explained in terms of the sun's behaviour. E.g., for most of the year at Lerwick, the sonde is affected by direct radiation from the sun at the time of the 0900 GMT observation, but at 100 mb, the sonde is also in sunlight at the time of the 0300 GMT observation for a period in the summer: in consequence the 100 mb, 0900-0300 GMT Lerwick curve (Figure 2(a)) is flat-topped. At Larkhill, on the other hand, the sonde is never affected by direct sunlight during the 0300 GMT ascent and the 100 mb, 0900-0300 GMT Larkhill curve (Figure 1(a)) therefore tends to have a sharper peak than the corresponding Lerwick curve.

Examination of the 1500-0300 GMT curves for Larkhill (Figure 1(e)) and Lerwick (Figure 2(e)) shows that the values based on estimated radiation errors underestimate the observed variations. A greater percentage underestimation occurs with the 0300-2100 GMT variations at Larkhill (Figure 1(d)) and Lerwick (Figure 2(d)). It must not be assumed that these systematic differences between the observed variations and those computed from estimated radiation errors are due to real diurnal changes in the temperature of the atmosphere. It is possible that the differences are due largely to inaccuracies in the estimated radiation errors, since a number of approximations necessarily had to be made both by Scrase, in evolving his technique for calculating radiation errors, and also by Vaisala in estimating the effect of absorption and scattering on the sun's radiation.

That the summer 0300-2100 GMT variations should be so far underestimated suggests that some factor which is particularly important at low solar altitudes has been insufficiently allowed for. One factor contributing to the discrepancy may be the neglect of the effect of radiation from the sky, as opposed to direct radiation from the sun. According to Landsberg (3), on clear days, at a solar altitude of 70 degrees, about 15% of the total radiation at ground level comes from the sky, while at a solar altitude of 10 degrees only 60% of the total radiation comes from the sun and 40% from the sky.

Figures 3(a) and 3(b) show that the observed diurnal variations are of similar magnitude at Malta and Nicosia. This is a surprising result since Nicosia is about 19 degrees farther east than Malta and, as the curves giving the variations due to estimated radiation errors show, the Malta 1500-0300 GMT variation would be expected appreciably to exceed the Nicosia variation on that account.

Whilst the estimated errors do not completely account for the observed variations, it is clear that they provide a reasonable basis for smoothing the curves computed from observations. Two methods of smoothing were tried experimentally on the 100 mb variations: (i) by relating the observed to the estimated variations by means of a regression equation; and (ii) by subtracting the estimated from the observed variations and smoothing the difference by taking weighted running means. Arguments can be advanced in favour of each of these two methods. Experiment showed that there was little difference between the smoothed curves obtained by the two methods. Method (ii) was adopted for all levels, since it is easier to apply and does not restrict the form of the curve to quite the same extent as Method (i). The smoothed curves were also adjusted slightly, (a) so as to be symmetrical about the solstices and (b) so that the sum of the 0900-0300 GMT and the 1500-0900 GMT variations should be equal and opposite to the sum of the 2100-1500 GMT and 0300-2100 GMT variations. Solar altitude varies symmetrically about the solstices and the effects of radiation on both the sonde and the atmosphere are functions of solar altitude. Moreover, in the early stages of this work, the first harmonics of the measured 1500-0300 GMT variations were calculated for Larkhill and Lerwick data. It was found that the position of the maximum of the sine curve, taking an average over all levels from 700 mb to 100 mb, occurred on the 22nd of June. Thus there is both theoretical and practical justification for adjustment (a). One effect of adjustment (b) is to remove those parts of the 6 hr variations which are due to the seasonal variation of contour height. Figure 6 contains graphs of the change of contour height in 24 hours due to the seasonal variation. After suitable smoothing these graphs would enable an analyst to allow for the seasonal variation of contour height if he wished, but at no season or level does the 24 hr change exceed 25 feet, a change which is synoptically unimportant.

The final smoothed versions of the observed diurnal variations curves are contained in Figures 7 to 9, where they may be compared with the unsmoothed observed diurnal changes. The root-mean-square difference between the observed and the final smoothed monthly values of the 6 hr variations, calculated for the Larkhill and Lerwick 100 mb data, was found to be 28.3ft. The standard errors of the December and June monthly mean 6 hr changes at Larkhill and Lerwick as deduced from the standard deviations of the individual 6 hr changes have a mean (r.m.s.) value of 31.4 ft, which suggests that the degree of smoothing attained is of the correct order.

For over half the year the sonde is in darkness at both 2100 GMT and at 0300 GMT over British stations. It will be noted from Figures 7(d) and 8(d) that during this period, there is a small negative 0300-2100 GMT variation. This corresponds to the nocturnal cooling, of about $\frac{1}{2}^{\circ}$F per 6 hr in the lower stratosphere, found by Kay (4).

4. Practical application

Figures 7, 8 and 9 enable corrections to be made to observations from Larkhill, Lerwick, Malta and Nicosia to remove the diurnal variation. For practical purposes it may be found more convenient to use a set of tables, such as Tables 3(a) to 3(e), to reduce the observations to some standard time. Tables 3(a) to 3(e) contain the amount, to the nearest ten feet, which should be subtracted from 0900 GMT, 1500 GMT and 2100 GMT observations to make them comparable with 0300 GMT observations. Linear interpolation is sufficiently accurate to give the reduction applicable to any day of the year from these tables. By suitable interpolation between the Larkhill and Lerwick values, similar tables could be constructed for any station in the British Isles.

5. The interdiurnal variation of contour height

If ϵ is the standard (random) error of measurement of the height of some pressure surface, S_{24} is the true interdiurnal variation and t_{24} is the root-mean-square 24 hr variation of the measured height of the pressure surface then we can write,

$$t_{24}^2 = S_{24}^2 + 2\epsilon^2$$

/since .

since S_{24} and ϵ are independent.

Further, if δ is the systematic variation of measured contour height over a given 12 hr period, S_{12} is the r.m.s. 12 hr variation due to random synoptic changes and t_{12} is the r.m.s. variation of the measured 12 hr changes we also have,

$$t_{12}^2 = S_{12}^2 + 2\epsilon^2 + \delta^2 .$$

S_{12} and S_{24} are the variations which are synoptically important.

Figure 10 shows how S_{12} and S_{24} compare in magnitude with ϵ and δ at all levels in the winter and summer seasons. For the winter period, data relating to the three months Dec.-Feb. 1952-53 at Larkhill and Lerwick were combined. The summer variations refer to June 1948-51 at Larkhill. The 12 hr variations are for the period 1500 GMT to 0300 GMT and the 24 hr variations were calculated from 0300 GMT observations. The calculated S_{12} bear a reasonable relation to the calculated S_{24} except at 100 mb in June. The June 100 mb S_{24} however, was computed from only 39 observations. As can be seen from the diagram, the corresponding value of S_{24} calculated over a longer period from 1946-52 was smaller.

Figures 10(a) and 10(b) illustrate the peculiar difficulties which arise in the lower stratosphere, where both the random and systematic errors increase markedly with height while the true synoptic variations become smaller.

6. Summary and conclusions

The 6 hr and 12 hr apparent diurnal variations of the measured contour heights have been evaluated for levels up to 100 mb. at Larkhill, Lerwick, Malta and Nicosia. Calculated values of the apparent diurnal variation, based on estimates of the radiation errors made by Scrase, tend to underestimate the observed variation, but nevertheless provide a reasonable first approximation to the diurnal changes, except for the 0300-2100 GMT variation, when both ascents are made whilst the sun is low in the sky. Tables are given which enable contour heights computed from radio-sonde observations made by stations in the British Isles, Malta and Nicosia to be corrected for diurnal variation.

References

(1) Scrase, F.J. 1953 Air Ministry, Met. Res. Ctee., M.R.P. No. 836.

(2) Vaisala, V. 1948 Geophysica, Helsinki, 3, 39.

(3) Landsberg, H. 1945 Handbook of Meteorology, McGraw-Hill Book Co. Inc., New York. Section XII, 928.

(4) Kay, R.H. 1951 Quart. J. R. Met. Soc., 77, 427.

/TABLE 1.

TABLE 1. 6 HR VARIATIONS OF CONTOUR HEIGHT IN FEET COMPUTED FROM OBSERVATIONS (1948-51)

700 mb.

Period GMT	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0900-	Larkhill	7	1	13	7	6	17	6	7	7	8	6	9
0300	Lerwick	-3	-3	0	15	14	9	0	-2	1	2	-5	-1
1500-	Larkhill	-1	17	12	35	37	30	31	27	25	11	1	-5
0900	Lerwick	9	23	0	24	27	31	21	24	21	2	1	2
2100-	Larkhill	14	-2	-14	-18	-16	-9	-19	-18	-13	-3	-5	-1
1500	Lerwick	11	-2	-7	-11	-18	-23	-14	-10	-8	3	4	4
0300-	Larkhill	-8	-16	-18	-24	-25	-38	-10	-16	-19	-16	-11	11
2100	Lerwick	-22	-24	0	-26	-24	-17	-7	-12	-14	-7	0	0

500 mb.

Period GMT	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0900-	Larkhill	12	16	11	19	26	22	30	14	26	22	8	-5
0300	Lerwick	-11	3	6	35	27	35	14	24	13	13	-12	-1
1500-	Larkhill	14	10	29	49	20	58	47	50	24	11	21	0
0900	Lerwick	10	29	16	37	33	35	23	38	33	15	6	4
2100-	Larkhill	-9	-23	-24	-37	-41	-34	-56	-43	-30	-18	-4	-15
1500	Lerwick	-2	-12	-22	-37	-47	-34	-29	-40	-18	-10	-15	-8
0300-	Larkhill	-20	-3	-16	-29	-35	-46	-23	-21	-20	-15	-19	20
2100	Lerwick	-9	-11	9	-39	-30	-36	-12	-22	-28	-18	23	7

300 mb.

Period GMT	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0900-	Larkhill	29	27	51	52	81	75	88	52	52	40	28	-7
0300	Lerwick	24	-16	19	68	81	82	67	54	35	19	-7	10
1500-	Larkhill	30	47	64	76	56	94	60	76	65	59	37	3
0900	Lerwick	18	67	40	59	53	51	40	69	60	16	11	17
2100-	Larkhill	-69	-50	-106	-100	-81	-114	-109	-119	-95	-83	-44	-21
1500	Lerwick	-25	-55	-62	-100	-85	-59	-48	-106	-72	-33	-26	-27
0300-	Larkhill	-45	-24	-14	-28	-61	-55	-43	-9	-22	-16	-21	4
2100	Lerwick	-12	6	5	-13	-60	-74	-64	-17	-23	-2	22	3

200 mb.

Period GMT	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0900-	Larkhill	56	22	84	126	142	126	149	118	145	81	41	39
0300	Lerwick	-2	-6	68	133	113	131	105	106	85	51	4	26
1500-	Larkhill	81	84	86	71	42	121	88	88	38	80	20	35
0900	Lerwick	37	85	44	68	48	64	37	67	57	22	19	52
2100-	Larkhill	-93	-128	-162	-173	-119	-184	-179	-179	-141	-152	-67	-53
1500	Lerwick	-14	-94	-126	-145	-110	-104	-88	-147	-110	-63	-37	-50
0300-	Larkhill	-49	22	-8	-24	-71	-63	-53	-27	-42	-9	-6	5
2100	Lerwick	-48	-11	4	-21	-70	-91	-71	-26	-32	-10	22	9

100 mb.

Period GMT	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0900-	Larkhill	109	81	194	230	302	298	305	194	247	148	200	127
0300	Lerwick	46	64	151	268	216	253	218	247	184	160	45	26
1500-	Larkhill	110	93	84	57	42	121	93	117	63	121	-15	58
0900	Lerwick	165	61	39	55	88	72	89	72	52	62	25	119
2100-	Larkhill	-177	-212	-212	-300	-274	-309	-307	-307	-265	-255	-133	-186
1500	Lerwick	-126	-181	-172	-249	-221	-231	-207	-201	-218	-151	-118	-123
0300-	Larkhill	-25	31	-41	17	-68	-88	-68	8	-31	-5	-50	-43
2100	Lerwick	-53	8	-17	-2	-80	-165	-95	-60	-9	-69	1	-41

/TABLE 2.

TABLE 2. 12 HR (1500 GMT-0300 GMT) VARIATION OF CONTOUR HEIGHT IN FEET COMPUTED FROM OBSERVATIONS

700 mb.

Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Larkhill	1948-52	-2	21	27	42	43	52	34	39	27	21	10	0
Lerwick	1948-52	-2	22	4	42	40	41	20	19	34	0	-3	2
Malta	1949-52	1	20	30	27.	56	45	35	41	20	6	17	-7
Nicosia	1948-52	20	16	40	40	55	59	36	52	43	21	12	8

500 mb.

Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Larkhill	1948-52	26	31	35	69	74	83	68	65	43	31	32	6
Lerwick	1948-52	7	22	17	74	77	73	45	58	38	28	-4	6
Malta	1949-52	17	38	69	83	102	68	69	48	48	36	34	9
Nicosia	1948-52	33	36	57	60	89	100	76	74	61	38	23	20

300 mb.

Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Larkhill	1948-52	81	74	85	133	135	175	152	134	114	92	68	11
Lerwick	1948-52	18	43	32	117	141	147	122	124	98	31	20	22
Malta	1949-52	50	86	67	87	191	123	94	101	97	74	59	20
Nicosia	1948-52	51	80	124	119	143	143	122	85	88	56	47	57

200 mb.

Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Larkhill	1948-52	129	102	159	211	194	247	224	218	176	153	72	62
Lerwick	1948-52	8	95	161	188	184	214	153	189	129	84	35	41
Malta	1949-52	65	127	92	138	249	177	126	125	119	96	92	42
Nicosia	1948-52	46	64	172	139	193	201	191	111	107	68	68	45

100 mb.

Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Larkhill	1948-52	172	162	248	322	364	388	404	328	294	254	224	140
Lerwick	1948-52	166	154	214	324	320	356	316	336	280	184	108	162
Malta	1949-52	161	174	230	238	370	212	211	237	203	216	138	121
Nicosia	1948-52	139	168	261	192	240	246	278	211	189	147	116	67

/TABLE 3.

TABLE 3. CORRECTIONS FOR DIURNAL VARIATION, IN TENS OF FEET, TO BE SUBTRACTED FROM OBSERVATIONS MADE AT THE STATED TIMES

(a) 700 mb.

		J.1	J.15	F.1	F.14	M.1	M.15	A.1	A.15	M.1	M.15	J.1	J.15	Jy.1	Jy.15	A.1	A.15	S.1	S.15	O.1	O.15	N.1	N.15	D.1	D.15
Lerwick	0900	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	1500	0	0	0	1	1	2	2	3	3	3	3	4	4	3	3	3	3	2	2	1	1	0	0	0
	2100	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	1	1	1	1
Larkhill	0900	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	1500	0	1	1	1	2	3	3	3	4	4	4	4	4	4	4	4	3	3	3	2	1	1	1	0
	2100	1	1	1	1	1	2	2	2	2	2	2	3	3	2	2	2	2	2	2	1	1	1	1	1
Malta	1500	0	0	1	1	2	2	3	3	4	4	4	4	4	4	4	4	3	3	2	2	1	1	0	0
Nicosia	1500	1	1	2	2	3	3	4	4	5	5	5	5	5	5	5	5	4	4	3	3	2	2	1	1

(b) 500 mb.

		J.1	J.15	F.1	F.14	M.1	M.15	A.1	A.15	M.1	M.15	J.1	J.15	Jy.1	Jy.15	A.1	A.15	S.1	S.15	O.1	O.15	N.1	N.15	D.1	D.15
Lerwick	0900	0	0	0	0	0	1	2	2	3	3	3	3	3	3	3	3	2	2	1	0	0	0	0	0
	1500	0	1	1	2	2	3	5	5	6	6	6	6	6	6	6	6	5	5	3	2	2	1	1	0
	2100	0	0	0	0	1	1	2	2	2	3	3	3	3	3	3	2	2	2	1	1	0	0	0	0
Larkhill	0900	0	1	1	1	1	1	2	2	2	3	3	3	3	3	3	2	2	2	1	1	1	1	1	0
	1500	1	2	2	3	3	4	5	6	6	7	7	7	7	7	7	6	6	5	4	3	3	2	2	1
	2100	0	1	1	1	1	2	2	2	2	3	3	3	3	3	3	2	2	2	2	1	1	1	1	0
Malta	1500	2	2	3	3	4	5	6	7	7	7	7	7	7	7	7	7	7	6	5	4	3	3	2	2
Nicosia	1500	2	3	3	3	4	5	6	7	7	8	9	9	9	9	8	7	7	6	5	4	3	3	3	2

(c) 300 mb.

		J.1	J.15	F.1	F.14	M.1	M.15	A.1	A.15	M.1	M.15	J.1	J.15	Jy.1	Jy.15	A.1	A.15	S.1	S.15	O.1	O.15	N.1	N.15	D.1	D.15
Lerwick	0900	0	0	0	1	1	2	4	5	6	7	8	8	8	8	7	6	5	4	3	1	1	0	0	0
	1500	2	2	3	4	5	7	9	11	12	13	13	13	13	13	13	12	11	9	7	5	4	3	2	2
	2100	0	0	0	0	0	0	1	2	3	5	6	6	6	6	5	3	2	1	0	0	0	0	0	0
Larkhill	0900	2	2	2	3	3	4	5	6	7	7	8	8	8	8	7	7	6	5	4	3	3	2	2	2
	1500	4	5	6	7	9	10	12	13	14	15	15	16	16	15	15	14	13	12	10	9	7	6	5	4
	2100	1	1	1	1	1	2	2	2	3	4	5	5	5	5	4	3	2	2	2	1	1	1	1	1
Malta	1500	4	5	5	6	7	8	9	10	11	11	12	12	12	12	11	11	10	9	8	7	6	5	5	4
Nicosia	1500	5	5	6	7	8	9	10	11	12	13	13	13	13	13	13	12	11	10	9	8	7	6	5	5

TABLE 3 (contd.)

(d) 200 mb.

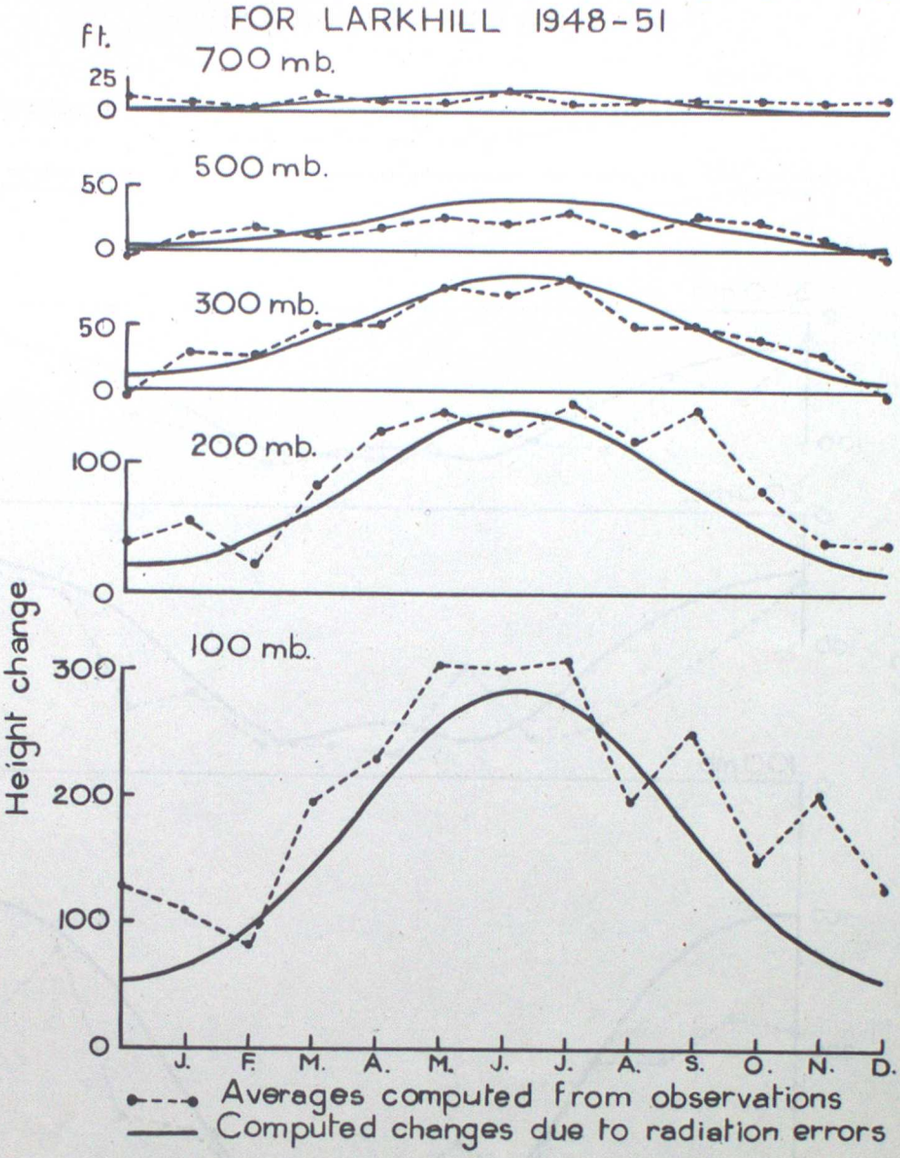
		J.1	J.15	F.1	F.14	M.1	M.15	A.1	A.15	M.1	M.15	J.1	J.15	Jy.1	Jy.15	A.1	A.15	S.1	S.15	O.1	O.15	N.1	N.15	D.1	D.15
Lerwick	0900	0	1	2	3	5	6	8	10	11	12	12	12	12	12	12	11	10	8	6	5	3	1	1	0
	1500	4	5	6	7	9	11	14	16	17	18	18	18	18	18	18	17	16	14	11	9	7	6	5	4
	2100	1	1	1	1	1	1	2	2	4	6	7	8	8	7	6	4	2	2	1	1	1	1	1	1
Larkhill	0900	4	4	5	6	7	9	11	12	13	14	14	14	14	14	14	13	12	11	9	7	6	5	4	4
	1500	9	9	10	12	14	16	18	19	21	22	23	23	23	23	22	21	19	18	16	14	12	10	9	9
	2100	2	1	1	1	1	1	2	3	3	5	5	6	6	5	5	3	3	2	1	1	1	1	1	2
Malta	1500	6	7	8	9	10	11	12	13	15	16	16	16	16	16	16	15	13	12	11	10	9	8	7	6
Nicosia	1500	5	5	6	8	9	11	12	14	15	17	19	19	19	19	17	15	14	12	11	9	8	6	5	5

(e) 100 mb.

		J.1	J.15	F.1	F.14	M.1	M.15	A.1	A.15	M.1	M.15	J.1	J.15	Jy.1	Jy.15	A.1	A.15	S.1	S.15	O.1	O.15	N.1	N.15	D.1	D.15
Lerwick	0900	3	4	7	10	13	16	19	21	23	25	25	24	24	25	25	23	21	19	16	13	10	7	4	3
	1500	15	15	15	16	18	21	24	27	30	33	33	33	33	33	33	30	27	24	21	18	16	15	15	15
	2100	3	3	2	2	2	2	2	3	6	10	11	11	11	11	10	6	3	2	2	2	2	2	3	3
Larkhill	0900	11	11	12	13	15	17	20	23	25	28	30	30	30	30	28	25	23	20	17	15	13	12	11	11
	1500	17	18	19	20	23	25	28	31	34	36	38	39	39	38	36	34	31	28	25	23	20	19	18	17
	2100	1	1	1	1	1	1	2	2	2	4	7	9	9	7	4	2	2	2	1	1	1	1	1	1
Malta	1500	13	14	15	17	19	21	23	24	25	25	24	24	24	24	25	25	24	23	21	19	17	15	14	13
Nicosia	1500	9	11	13	15	16	19	20	22	23	24	25	26	26	25	24	23	22	20	19	16	15	13	11	9

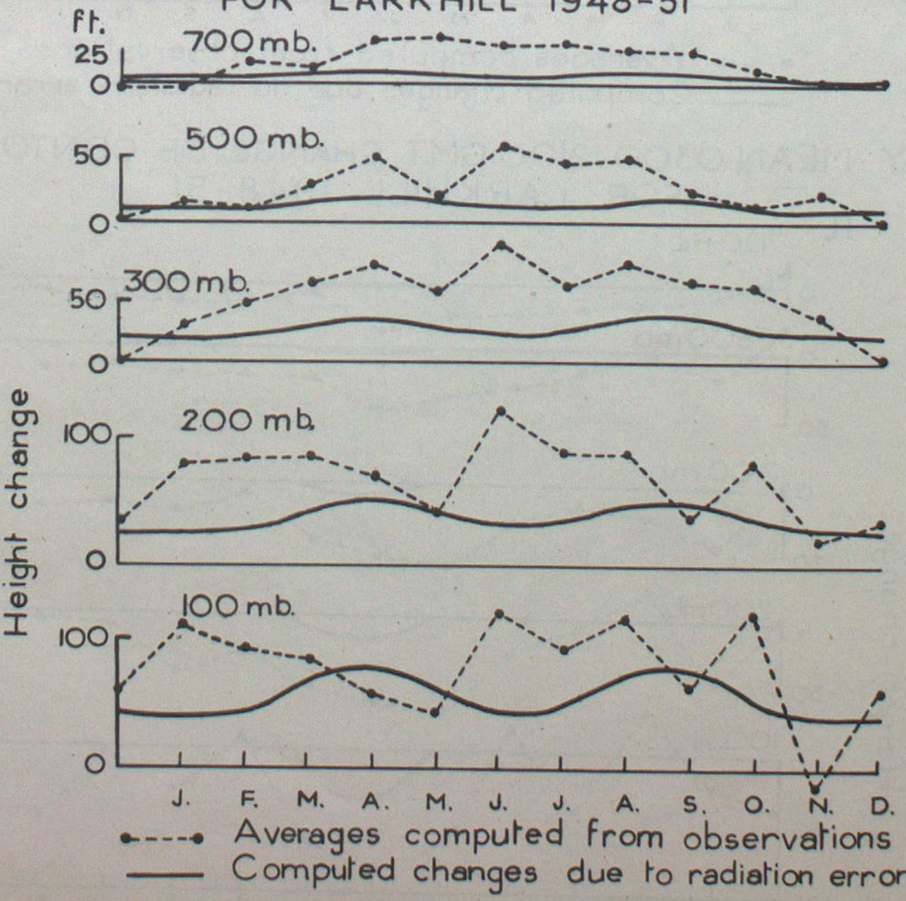
MONTHLY MEAN 0900-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 1(a)



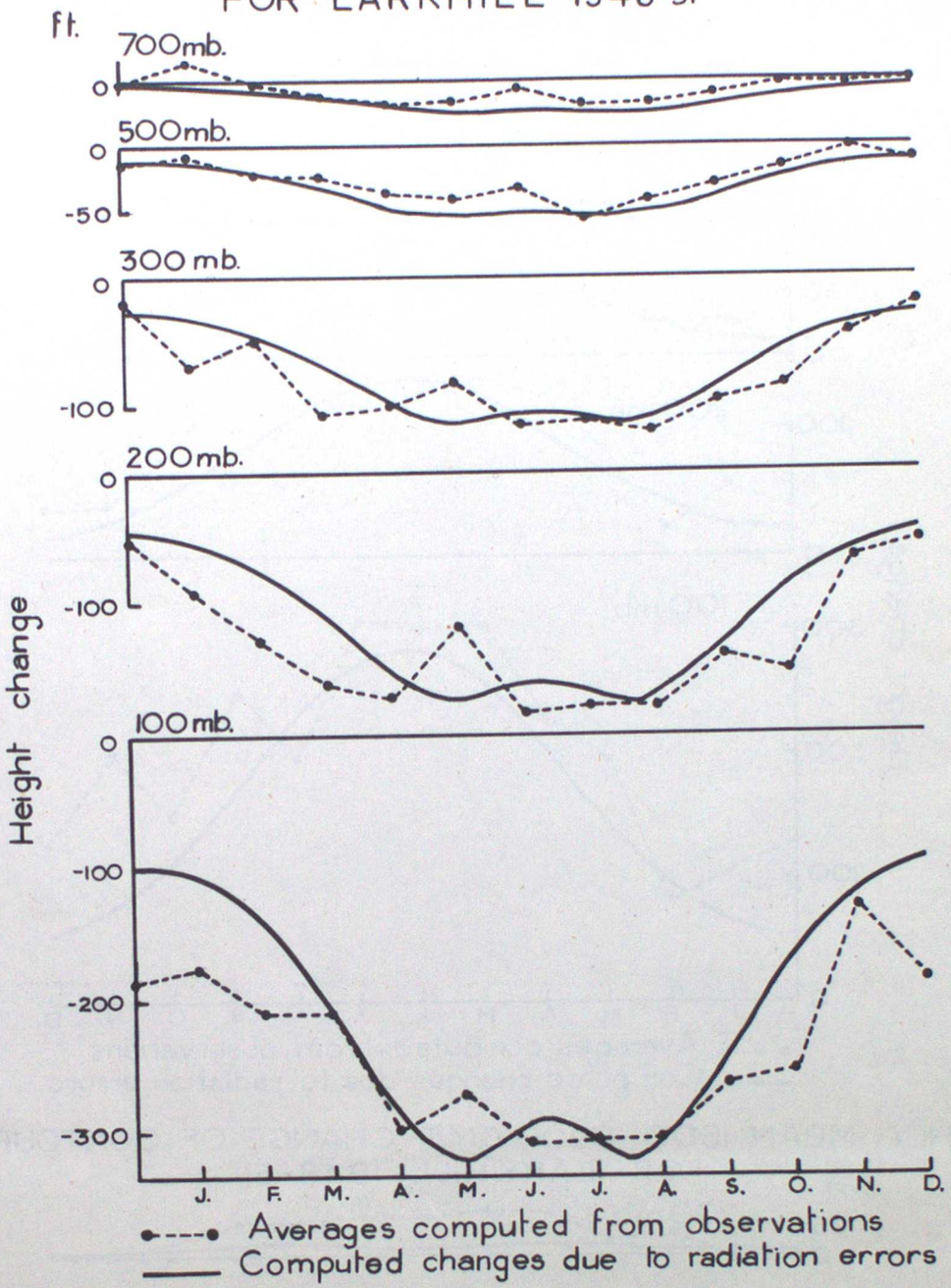
MONTHLY MEAN 1500-0900 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 1(b)



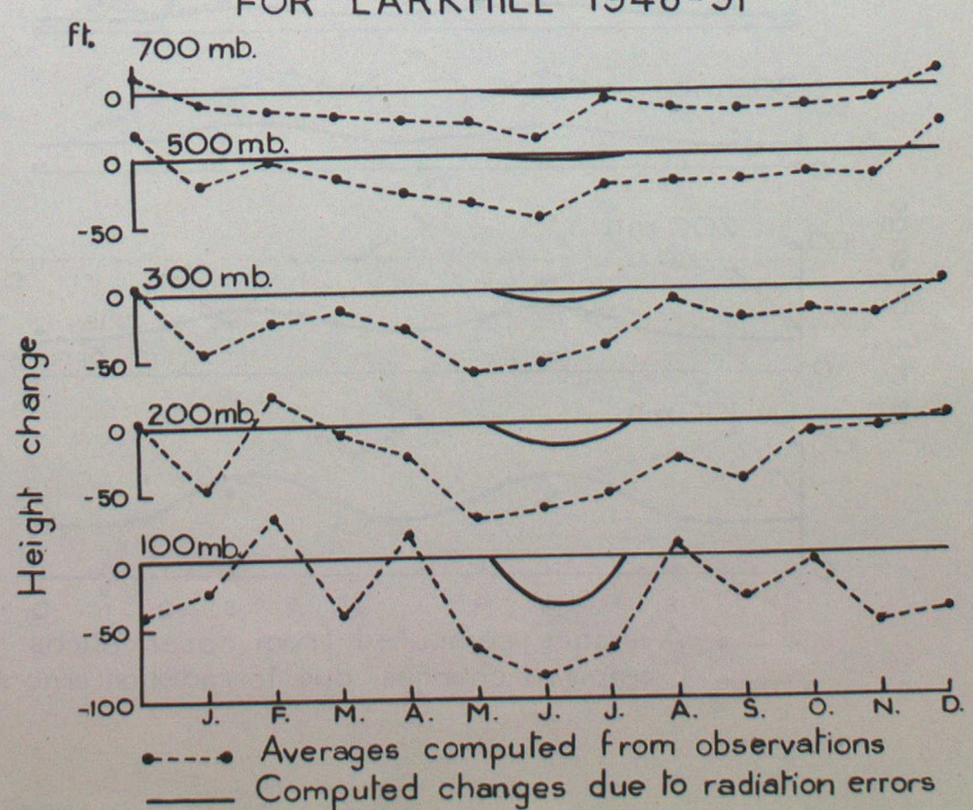
MONTHLY MEAN 2100-1500 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig.1(c)



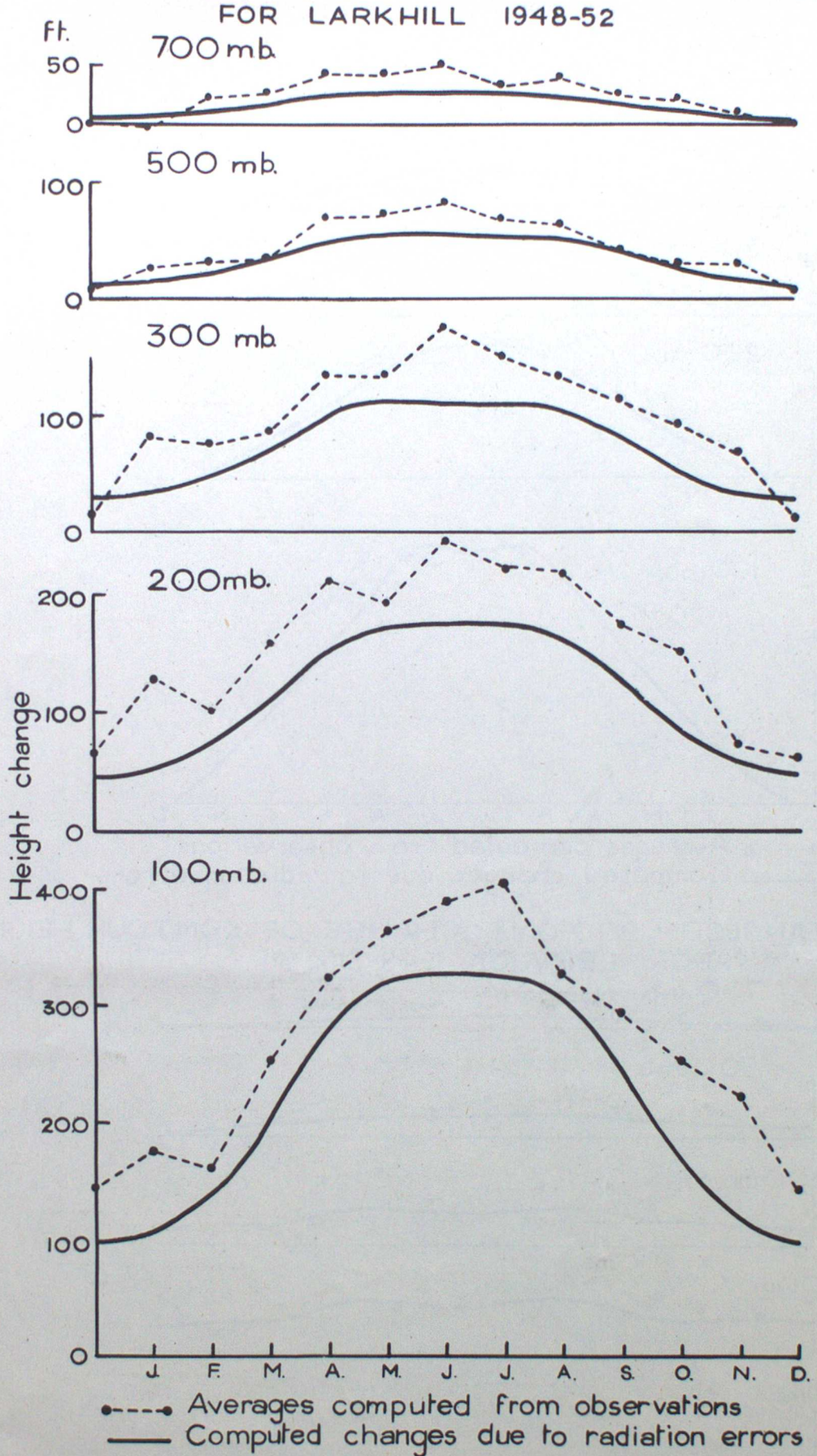
MONTHLY MEAN 0300-2100 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 1 (d)



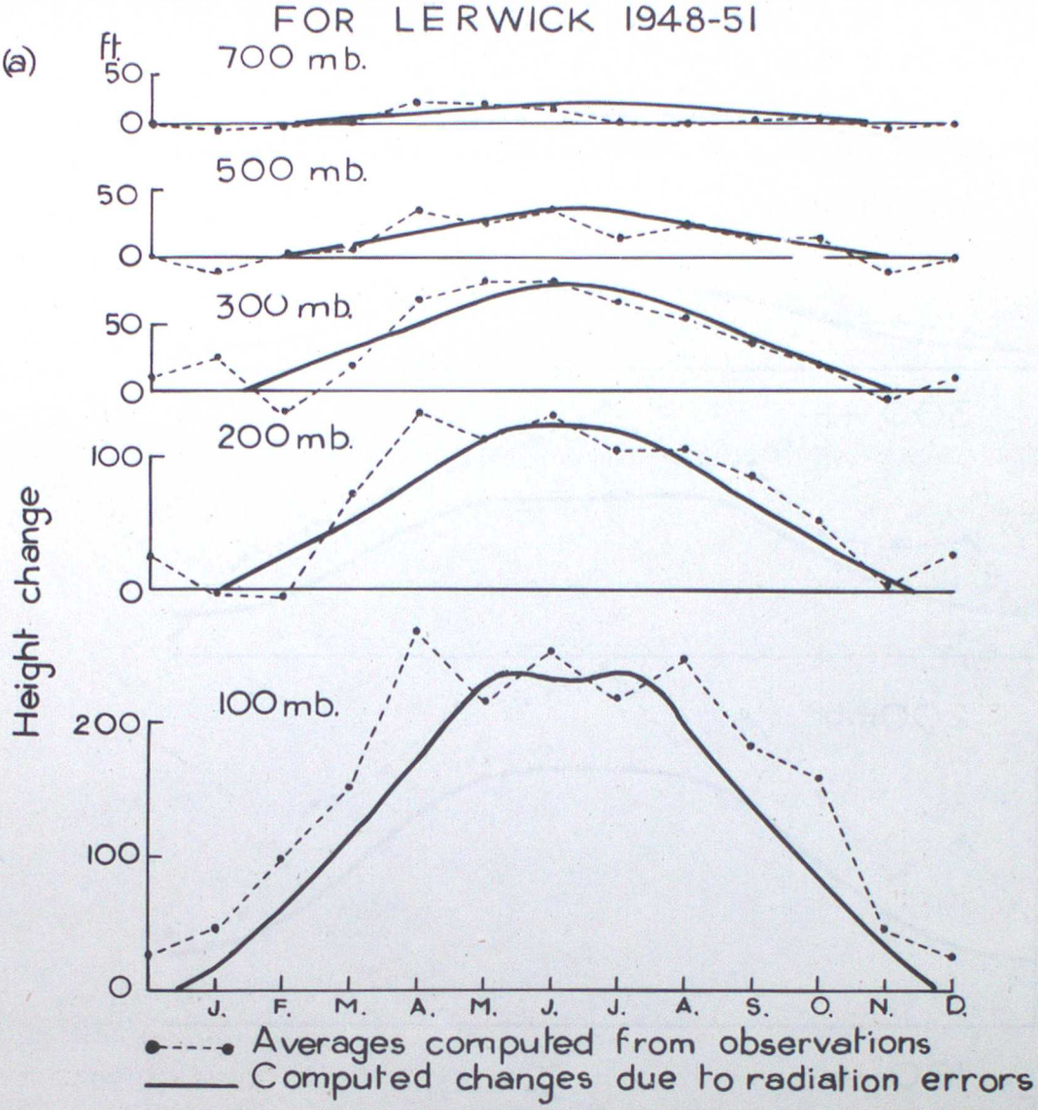
MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-52

Fig. 1(e)



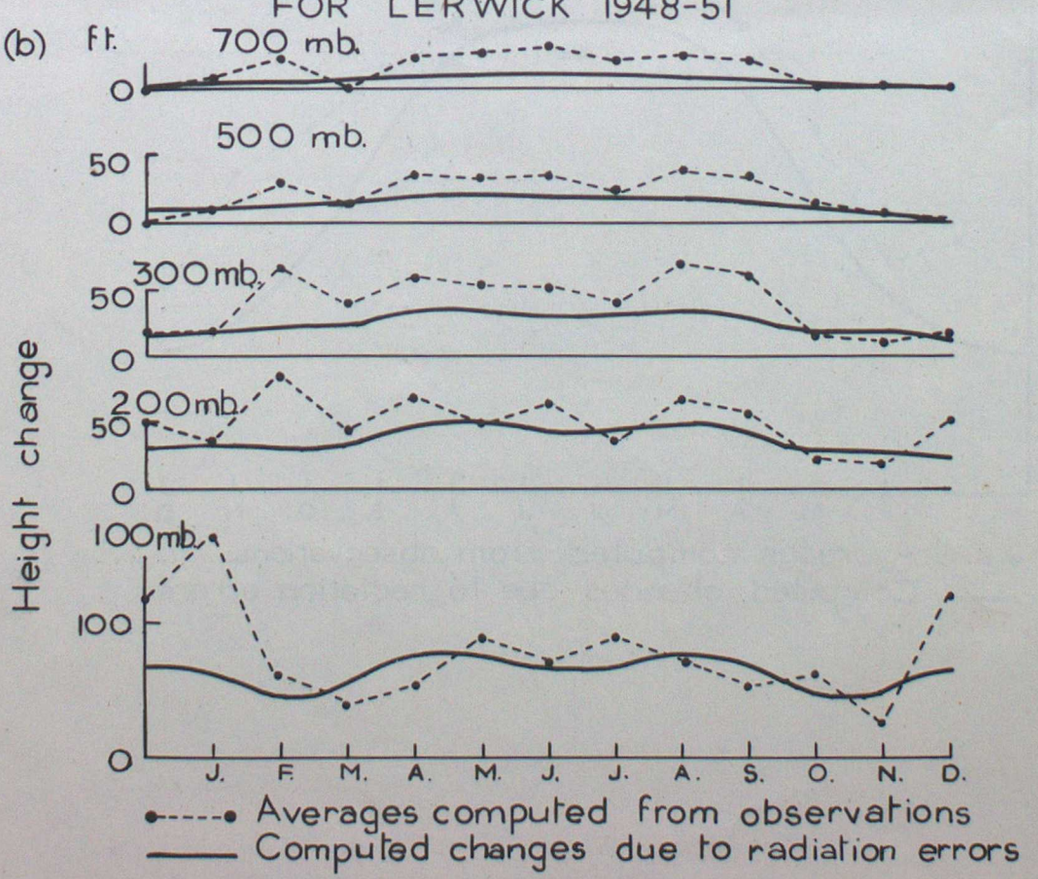
MONTHLY MEAN 0900-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 2(a)



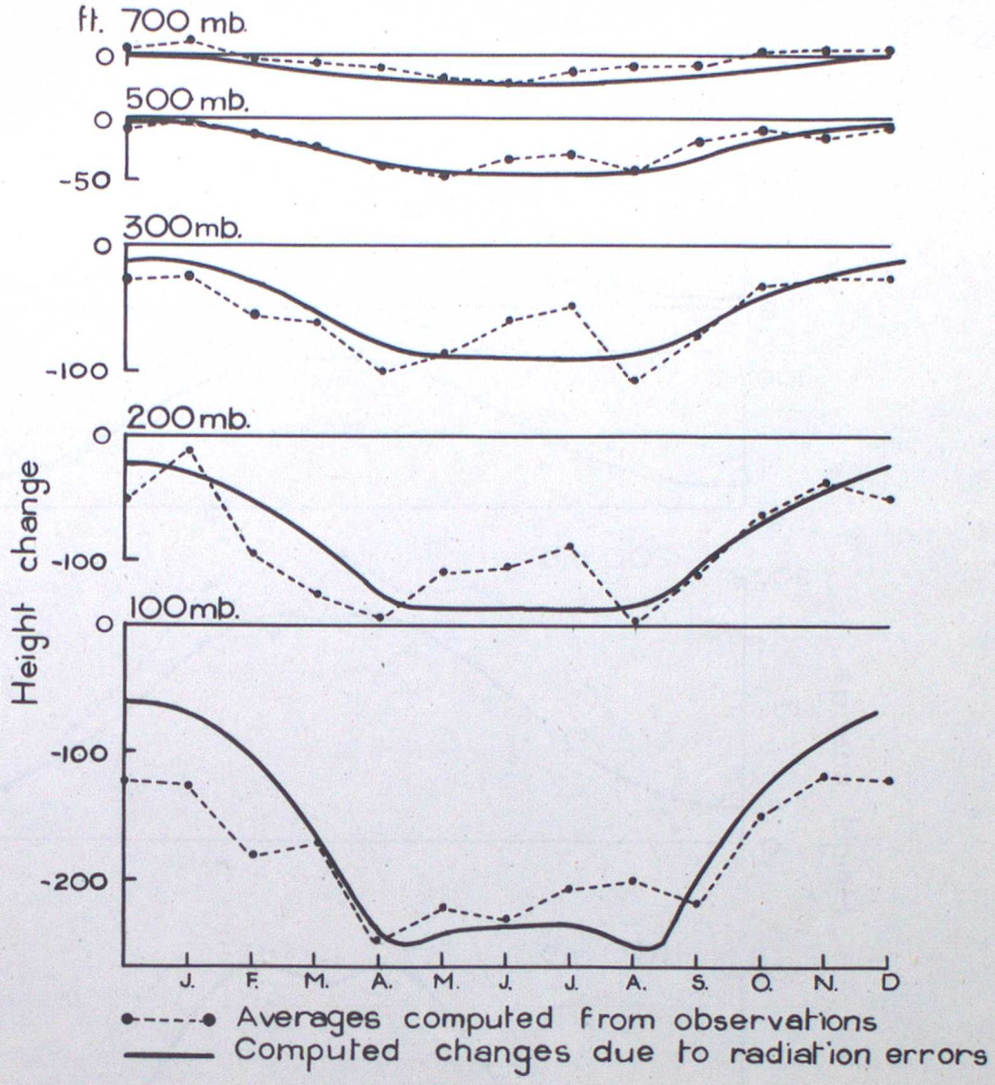
MONTHLY MEAN 1500-0900 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 2 (b)



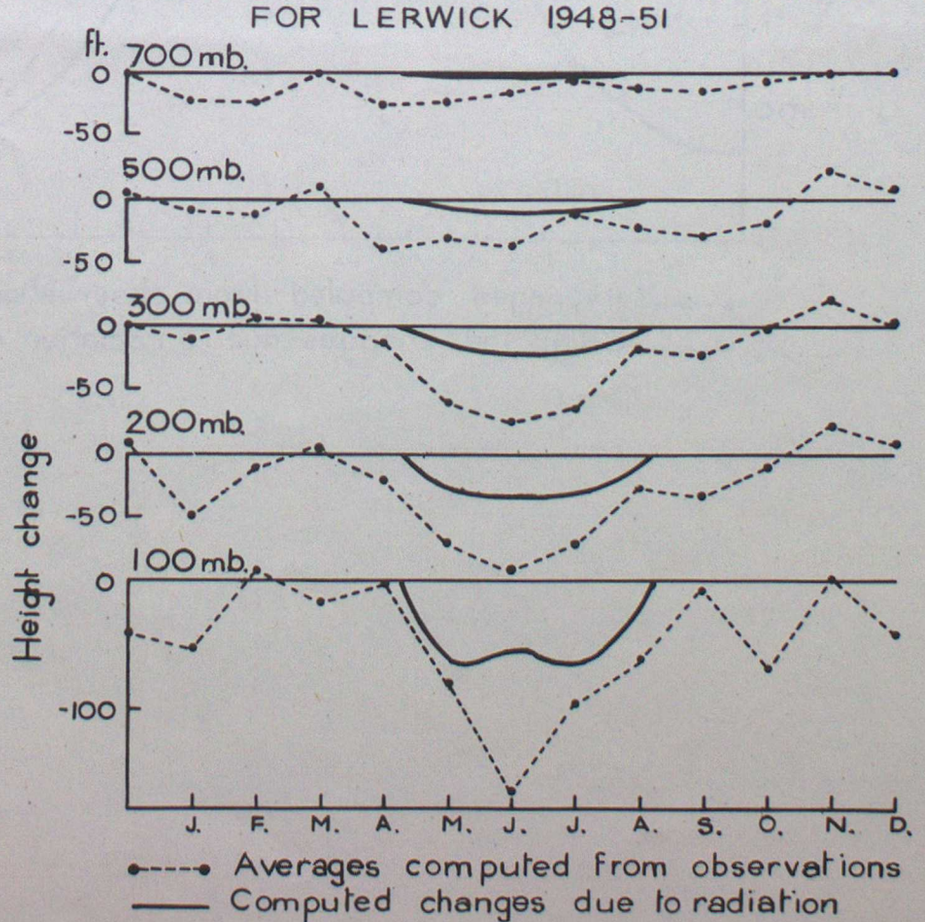
MONTHLY MEAN 2100 - 1500 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 2(c)



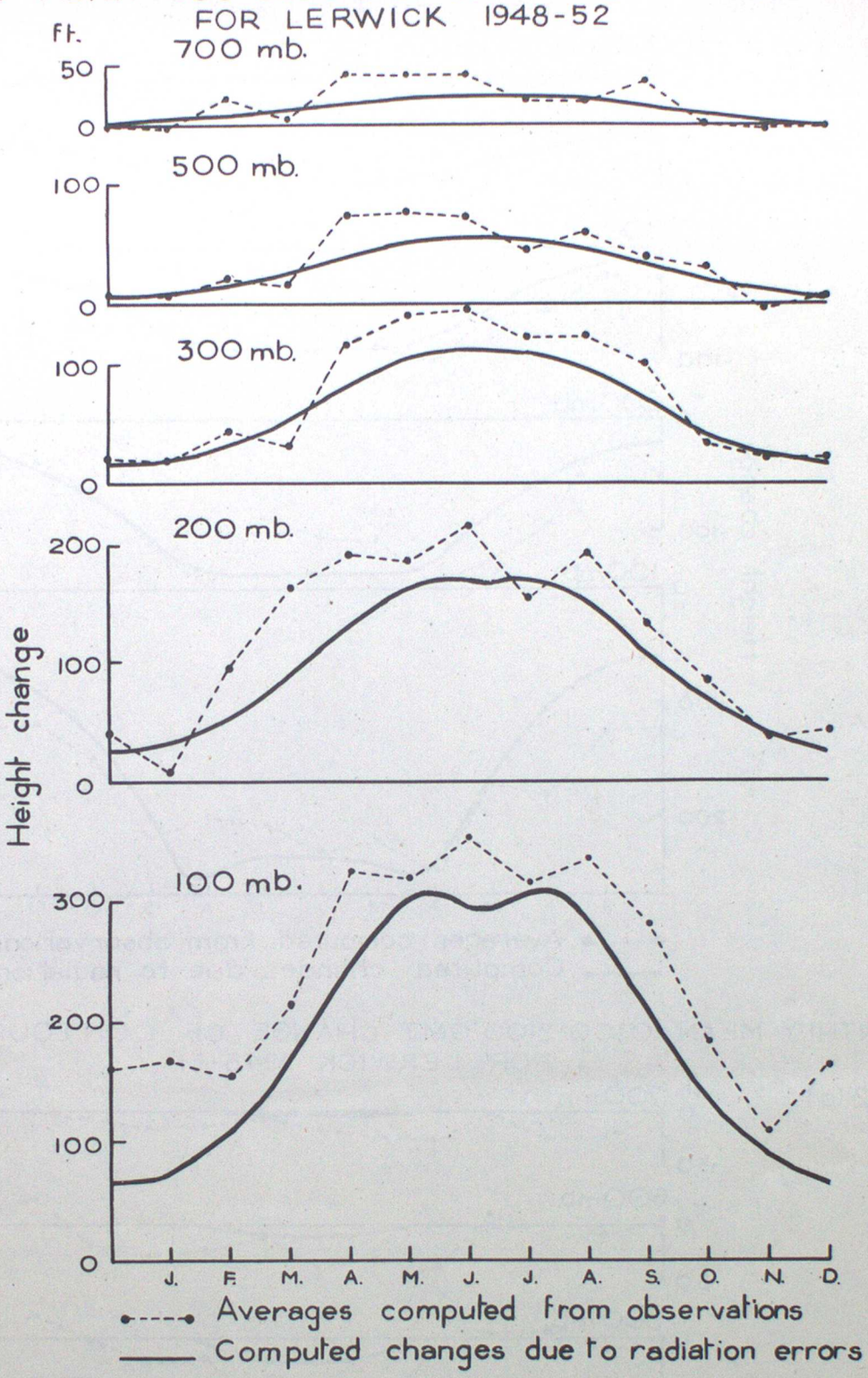
MONTHLY MEAN 0300-2100 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 2 (d)



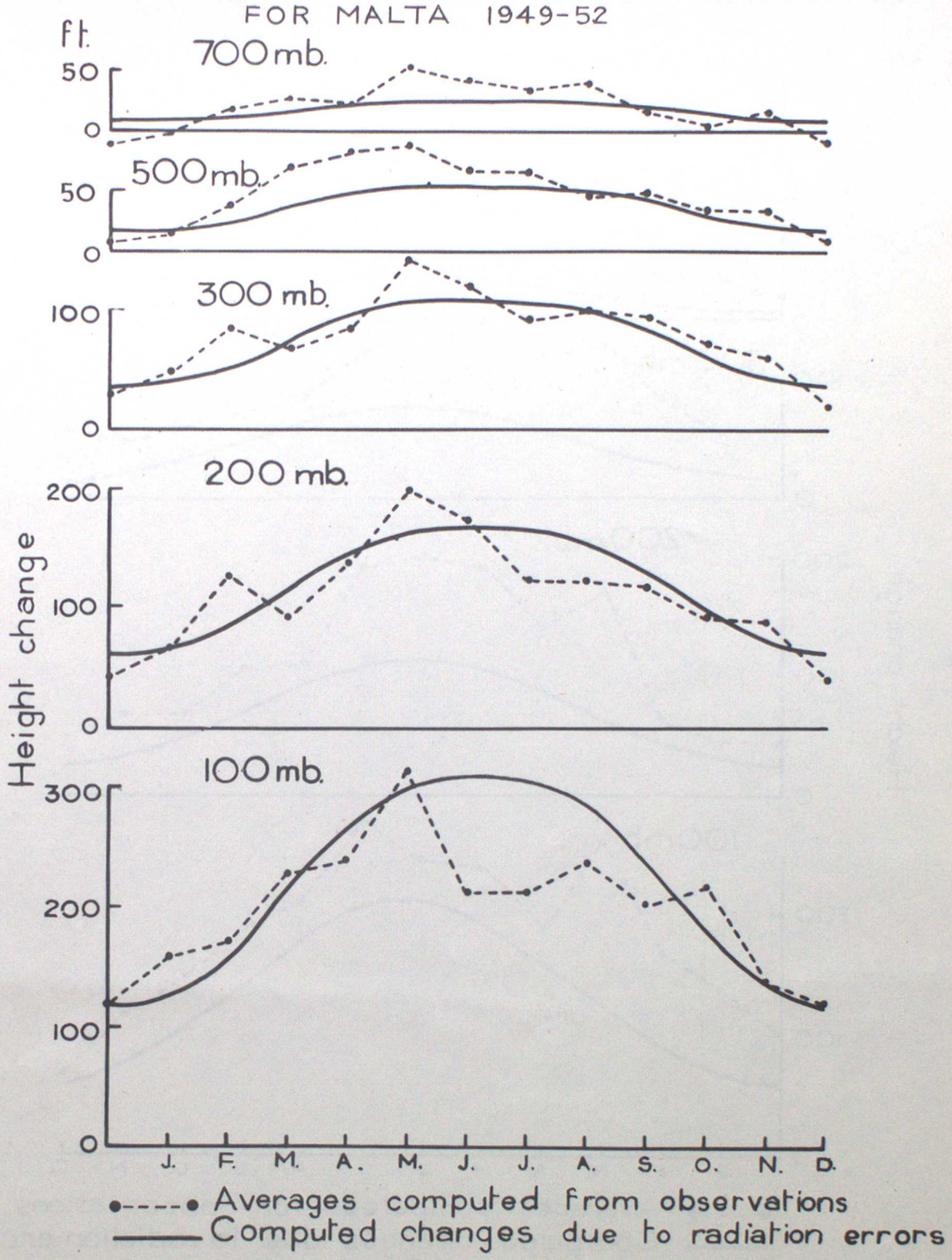
MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-52

Fig. 2 (e)



MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR MALTA 1949-52

Fig. 3(a)



MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR NICOSIA 1948-52

Fig. 3(b)

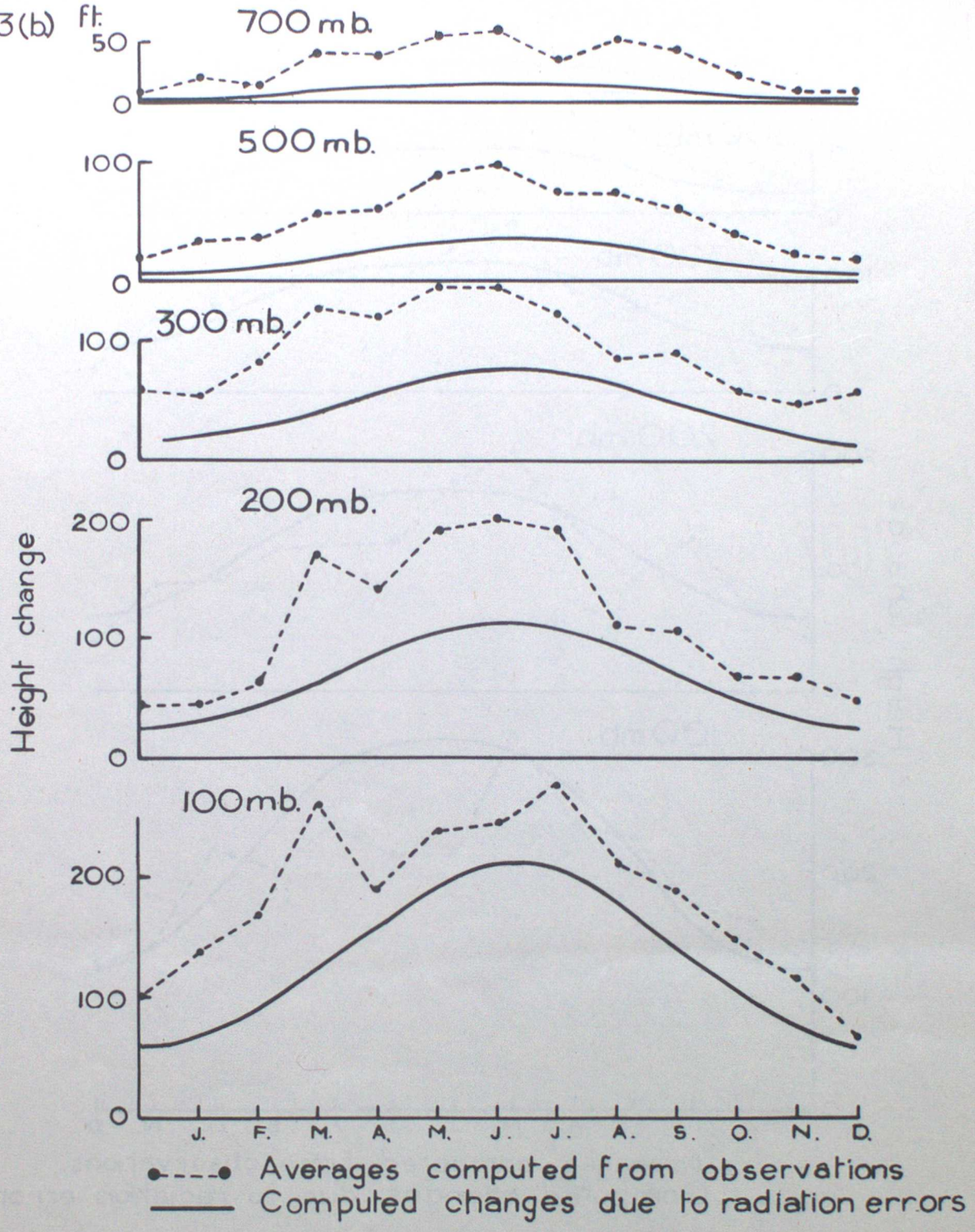


Fig.4 RADIATION ERRORS OF THE M.O. RADIO-SONDE

(a) Positive solar altitudes

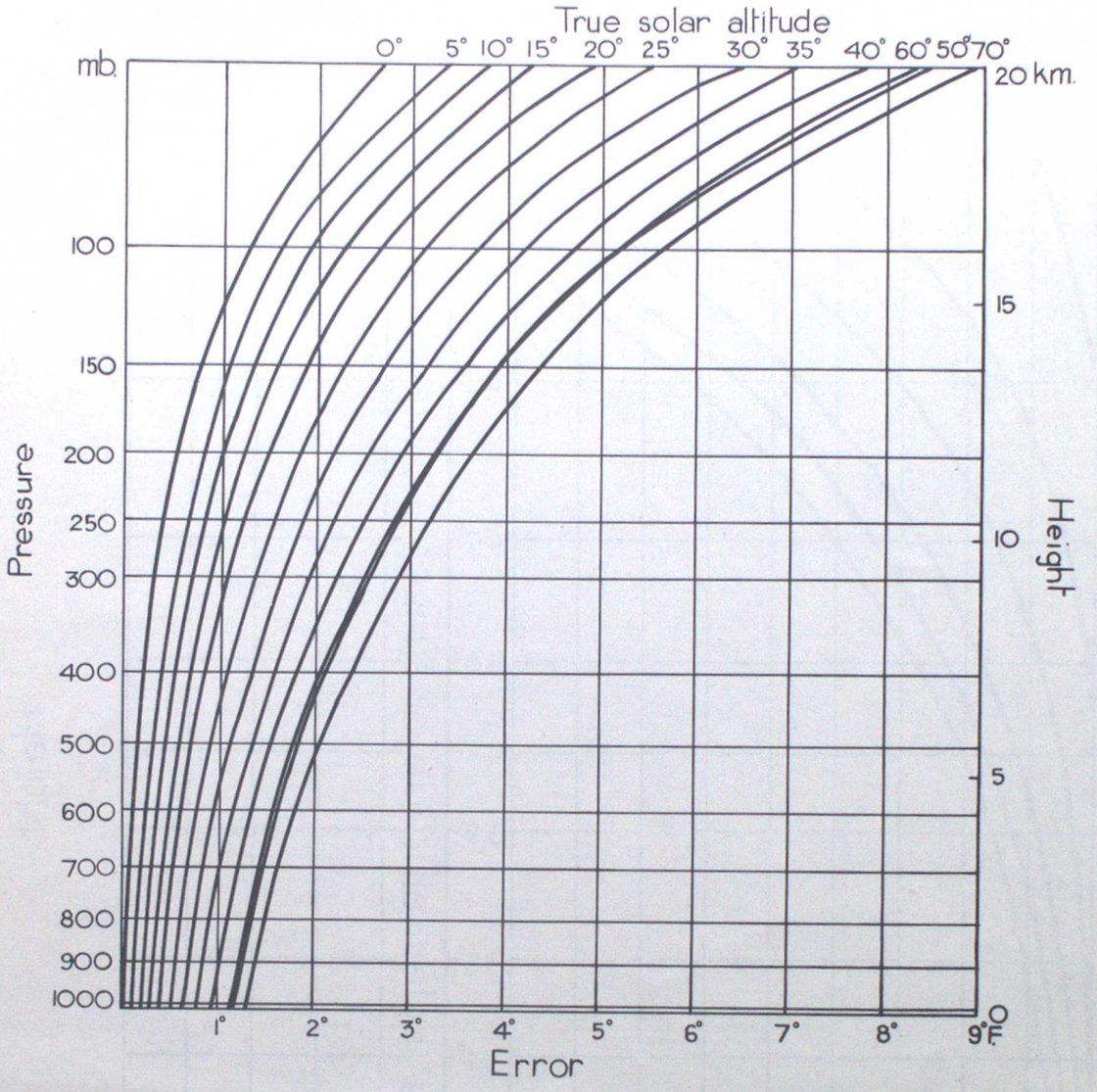


Fig.4 RADIATION ERRORS OF THE M.O. RADIO-SONDE

(b) Negative solar altitudes

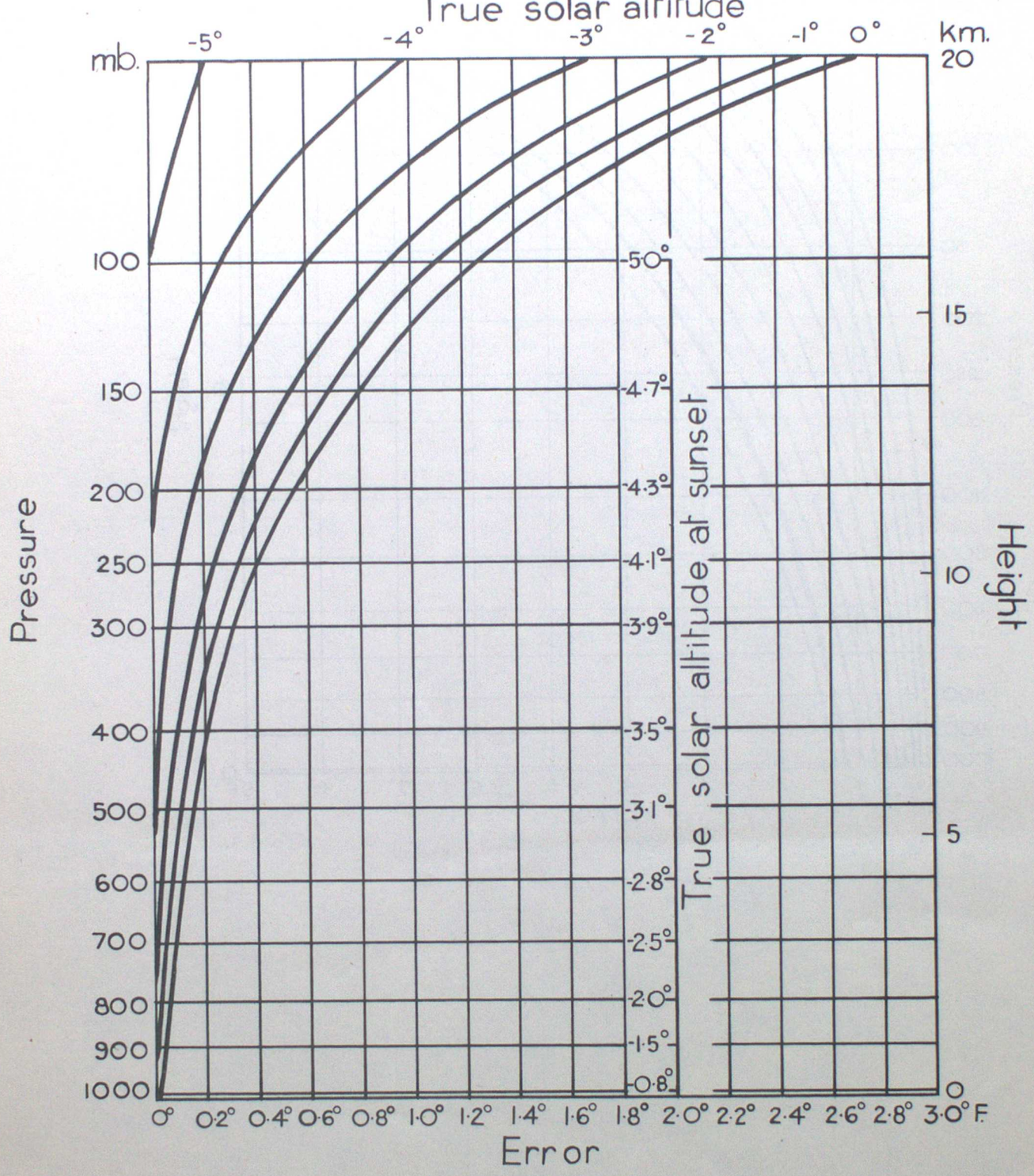
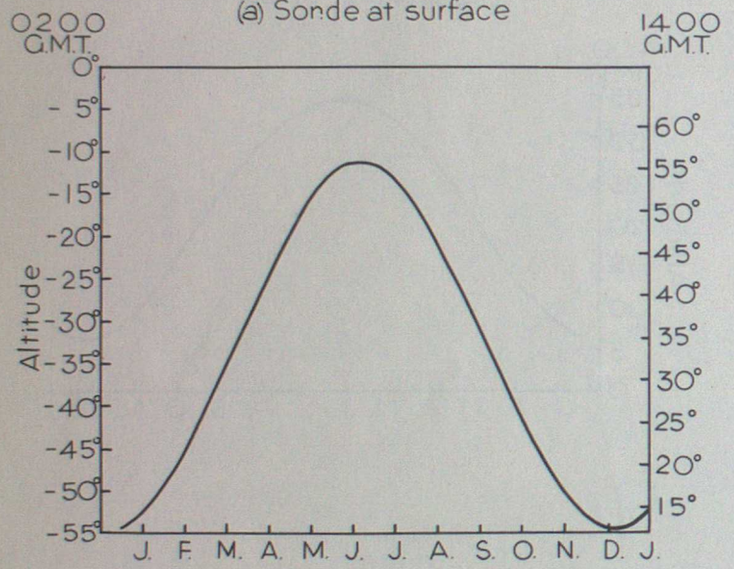


Fig. 5

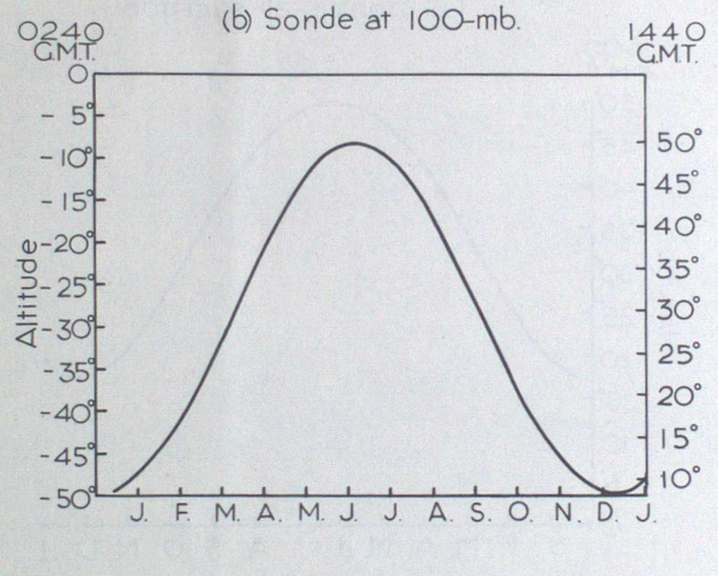
i) ANNUAL VARIATION OF SOLAR ALTITUDE AT LARKHILL (51°12'N., 1°48'W.)

(a) Sonde at surface



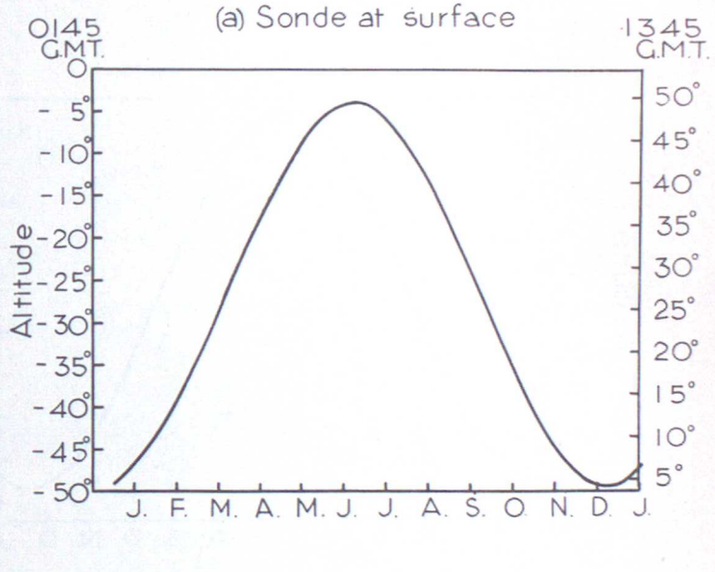
i) ANNUAL VARIATION OF SOLAR ALTITUDE AT LARKHILL (51°12'N., 1°48'W.)

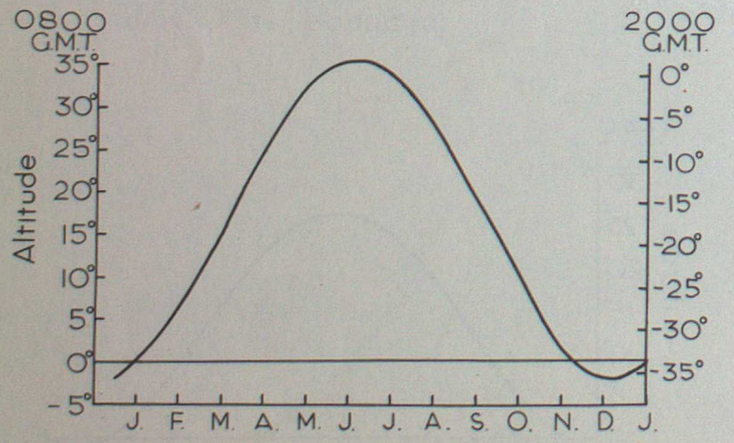
(b) Sonde at 100-mb.

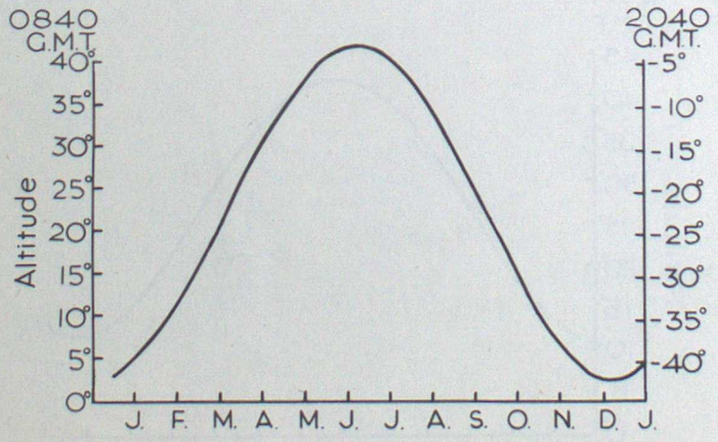


ii) ANNUAL VARIATION OF SOLAR ALTITUDE AT LERWICK (60°8'N., 1°11'W.)

(a) Sonde at surface







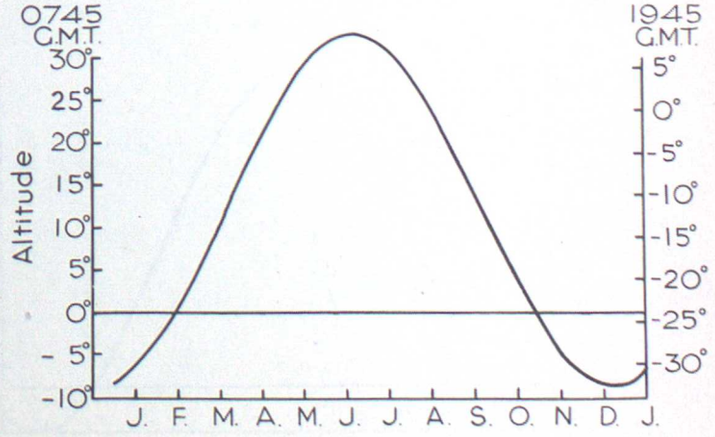
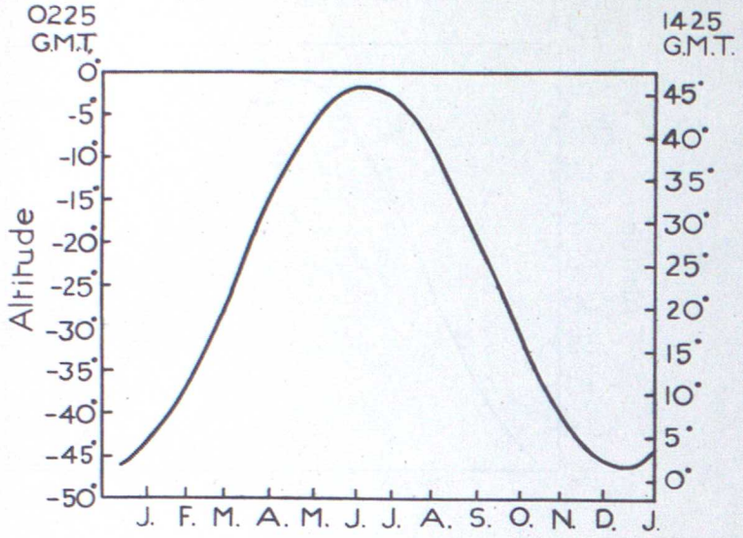


Fig. 5

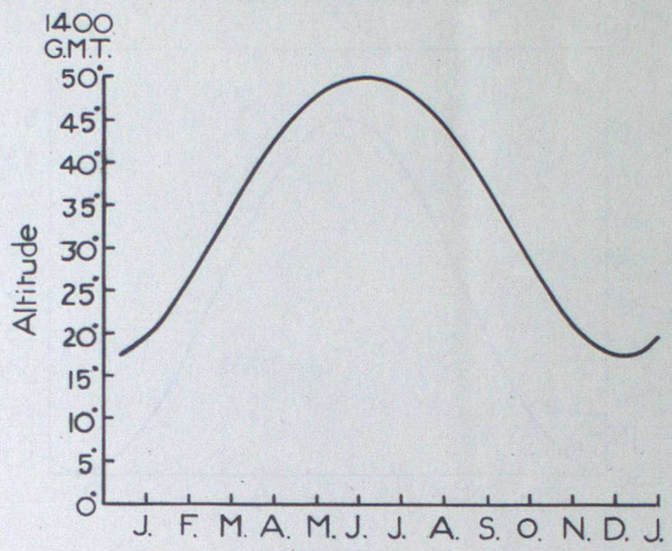
(ii) ANNUAL VARIATION OF SOLAR ALTITUDE AT LERWICK (60°8'N, 1°11'W)

(b) Sonde at 100 mb.

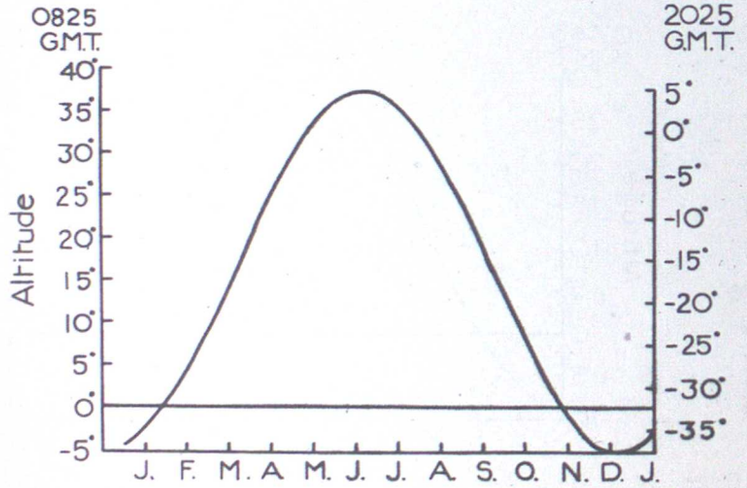


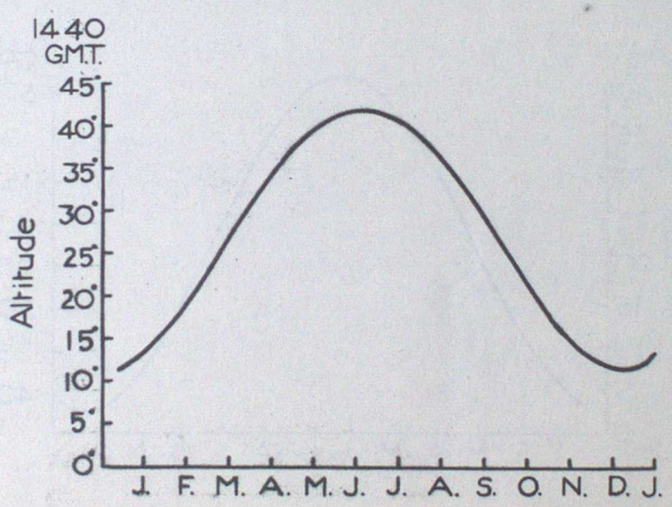
(iii) ANNUAL VARIATION OF SOLAR ALTITUDE AT MALTA (35°50'N, 14°27'E)

(a) Sonde at surface



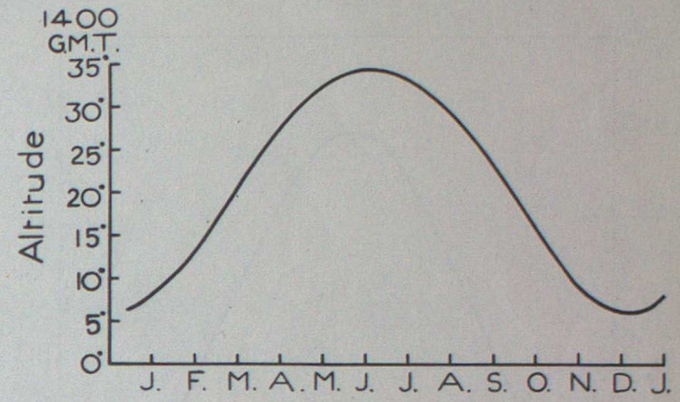
(b) Sonde at 100mb.





(iv) ANNUAL VARIATION OF SOLAR ALTITUDE AT NICOSIA (35°9'N, 33°17'E)

(a) Sonde at surface



(b) Sonde at 100mb.

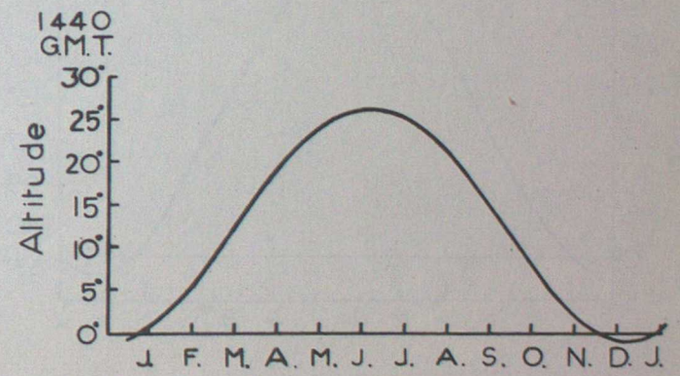
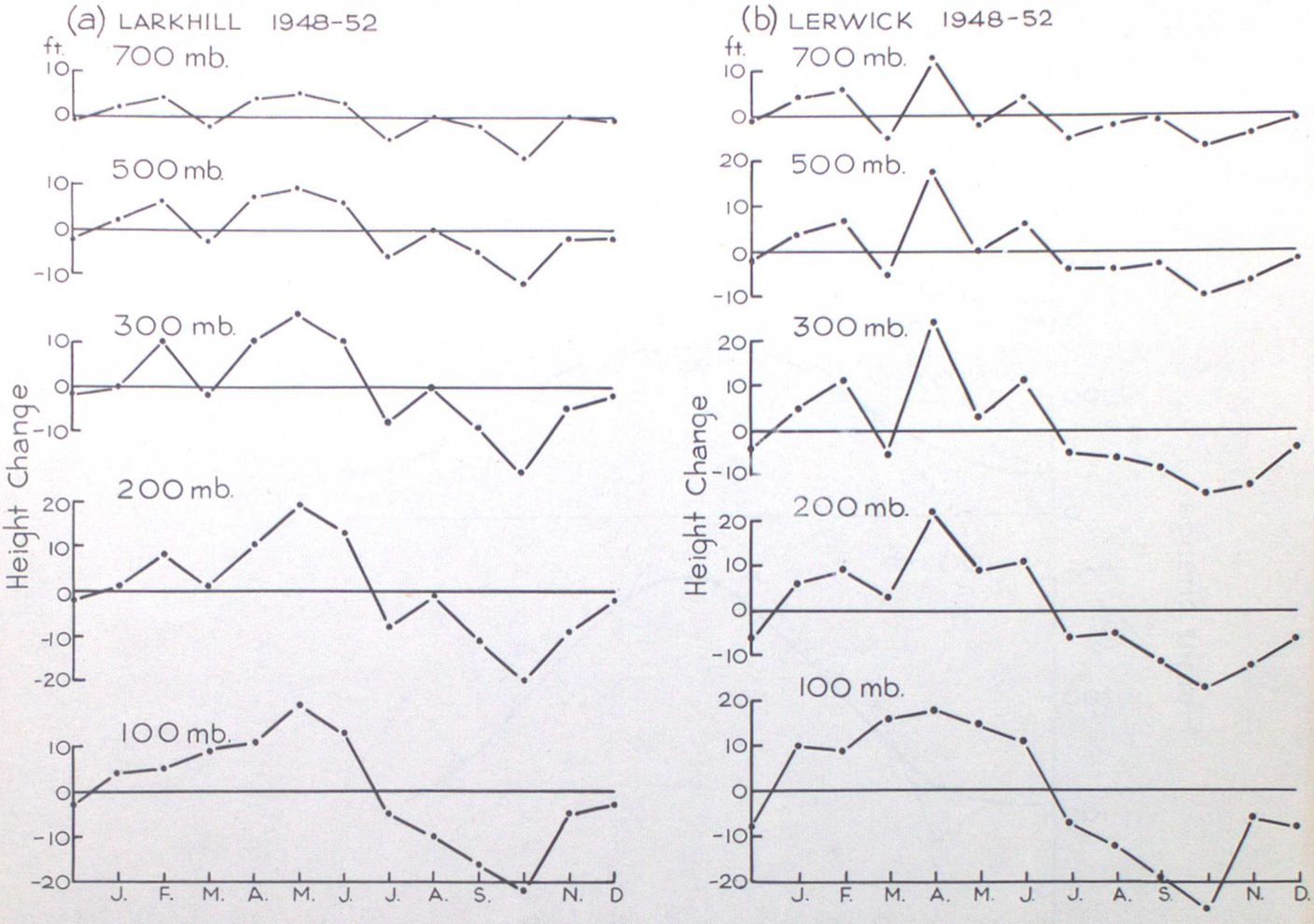
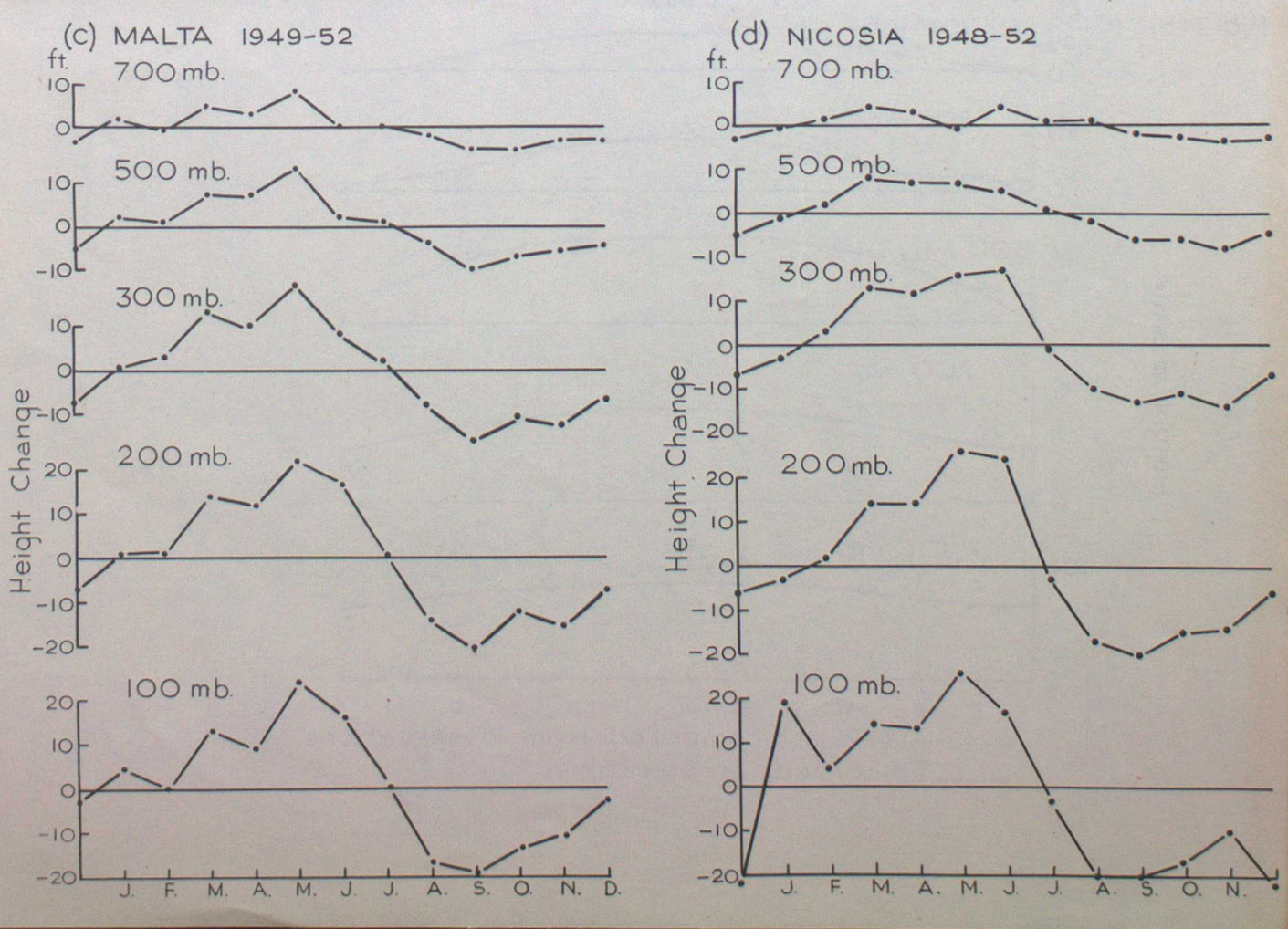


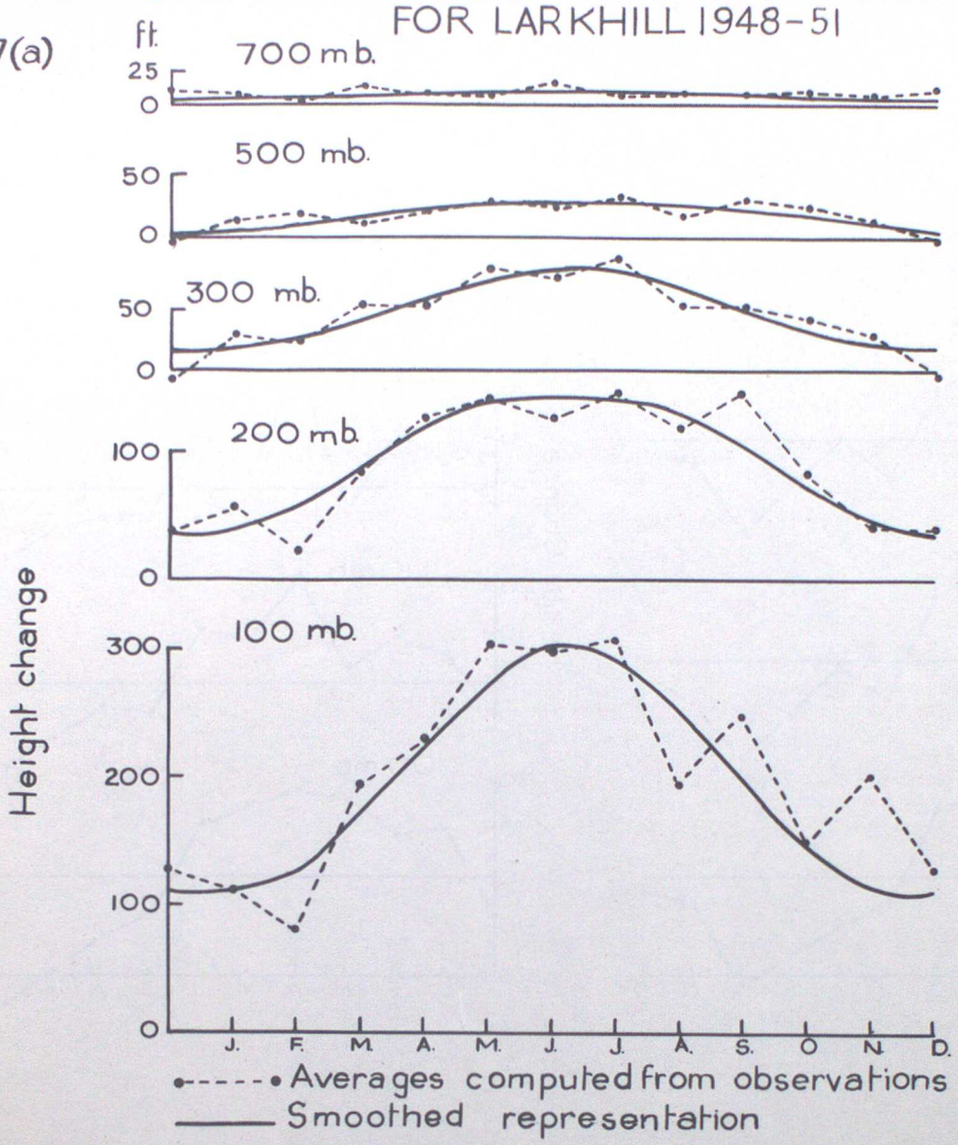
Fig. 6 CHANGE IN CONTOUR HEIGHT IN 24 HOURS DUE TO THE SEASONAL VARIATION OF CONTOUR HEIGHT





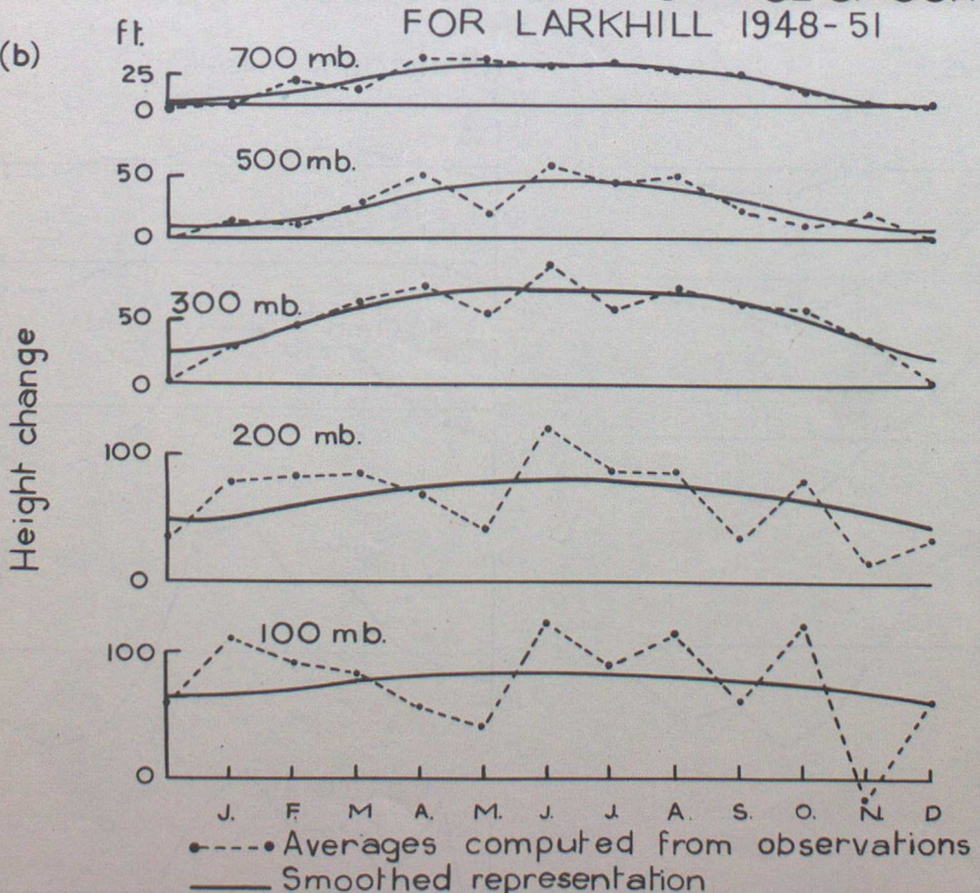
MONTHLY MEAN 0900-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 7(a)



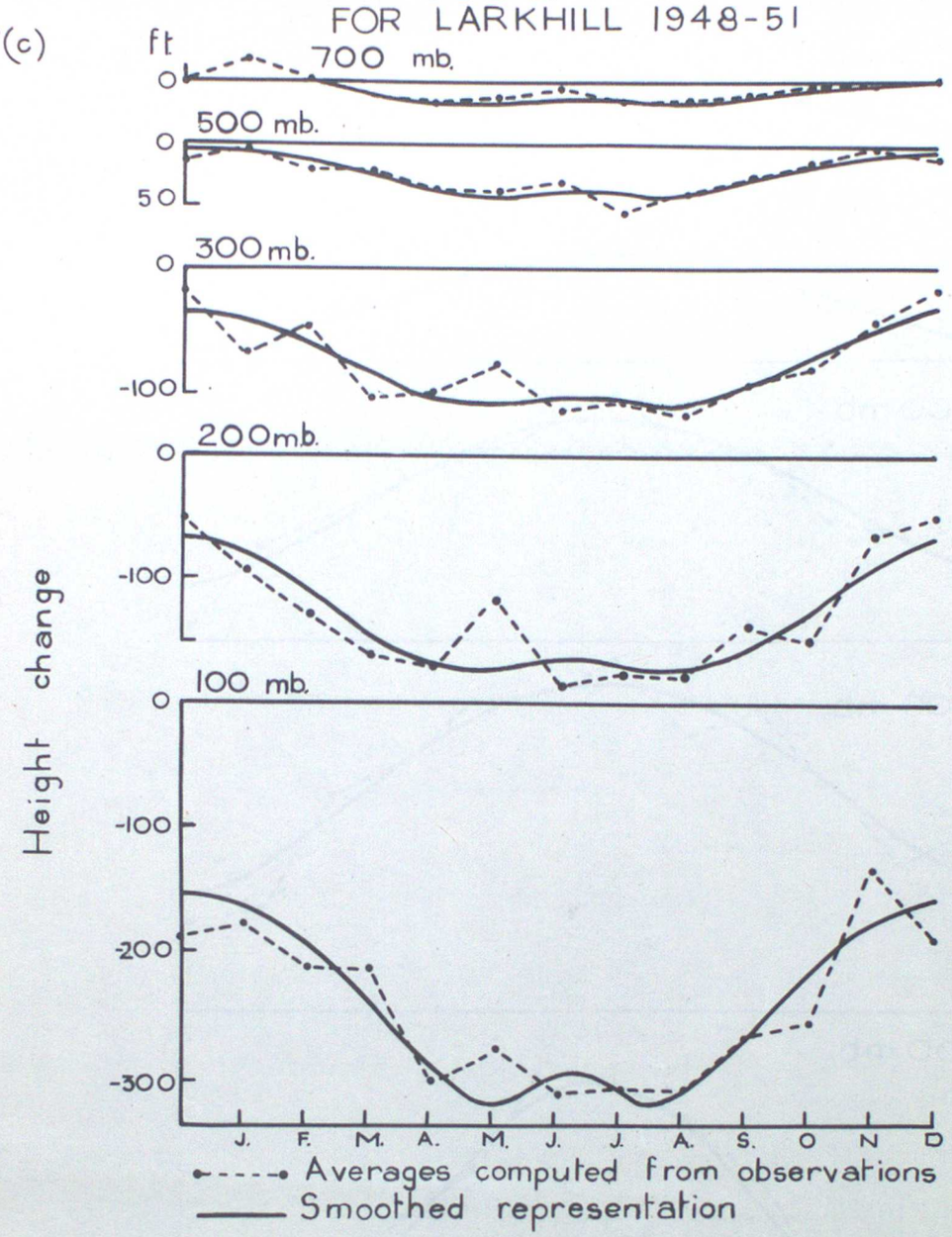
MONTHLY MEAN 1500-0900 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 7(b)



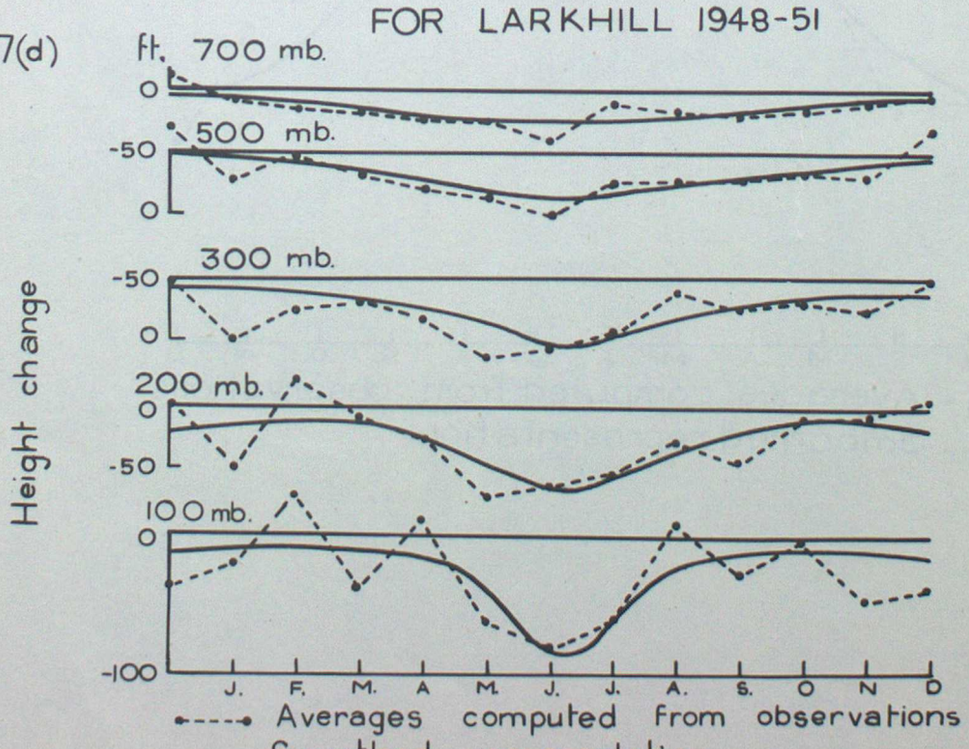
MONTHLY MEAN 2100-1500 G.M.T CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 7(c)



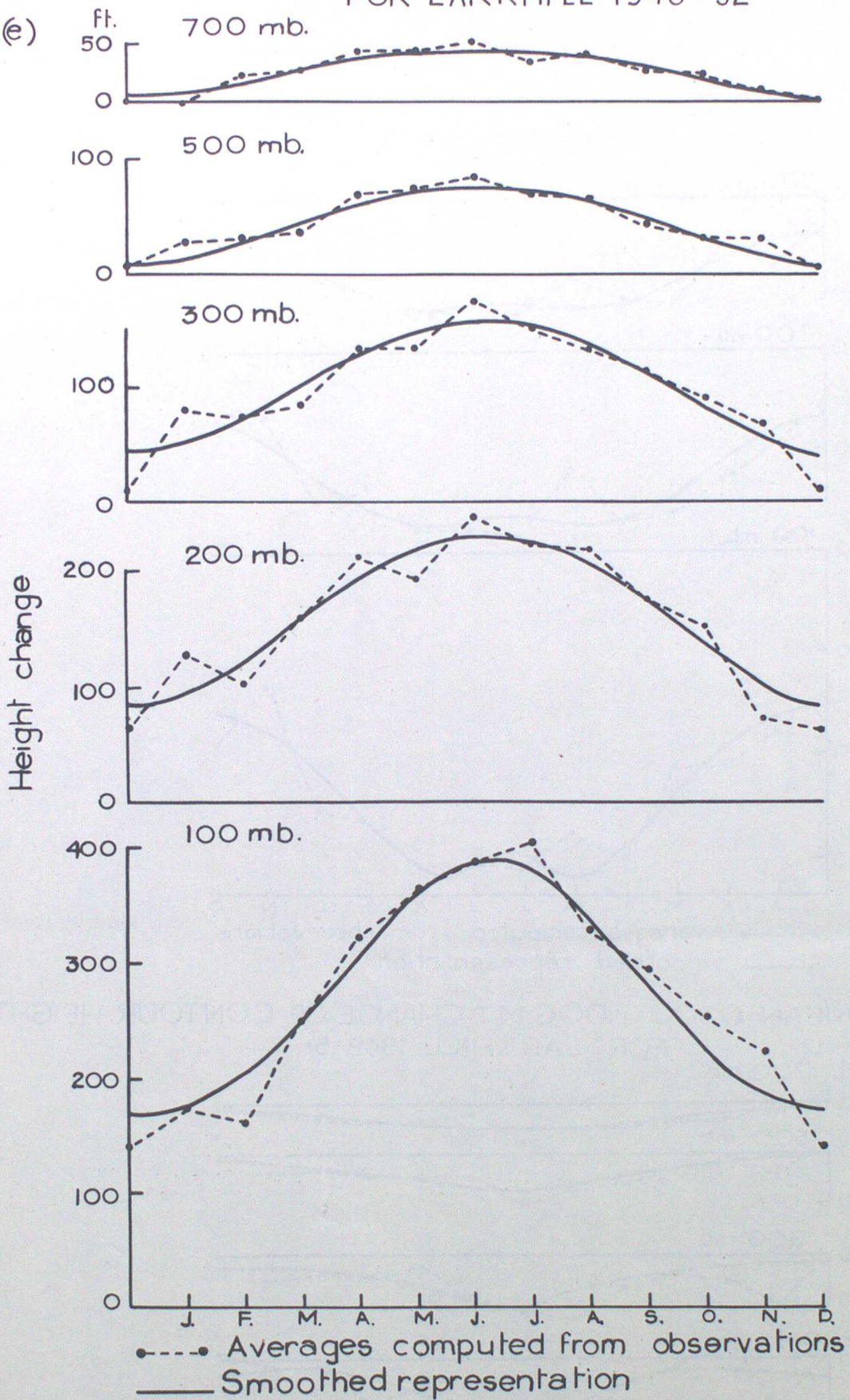
MONTHLY MEAN 0300-2100 G.M.T CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-51

Fig. 7(d)



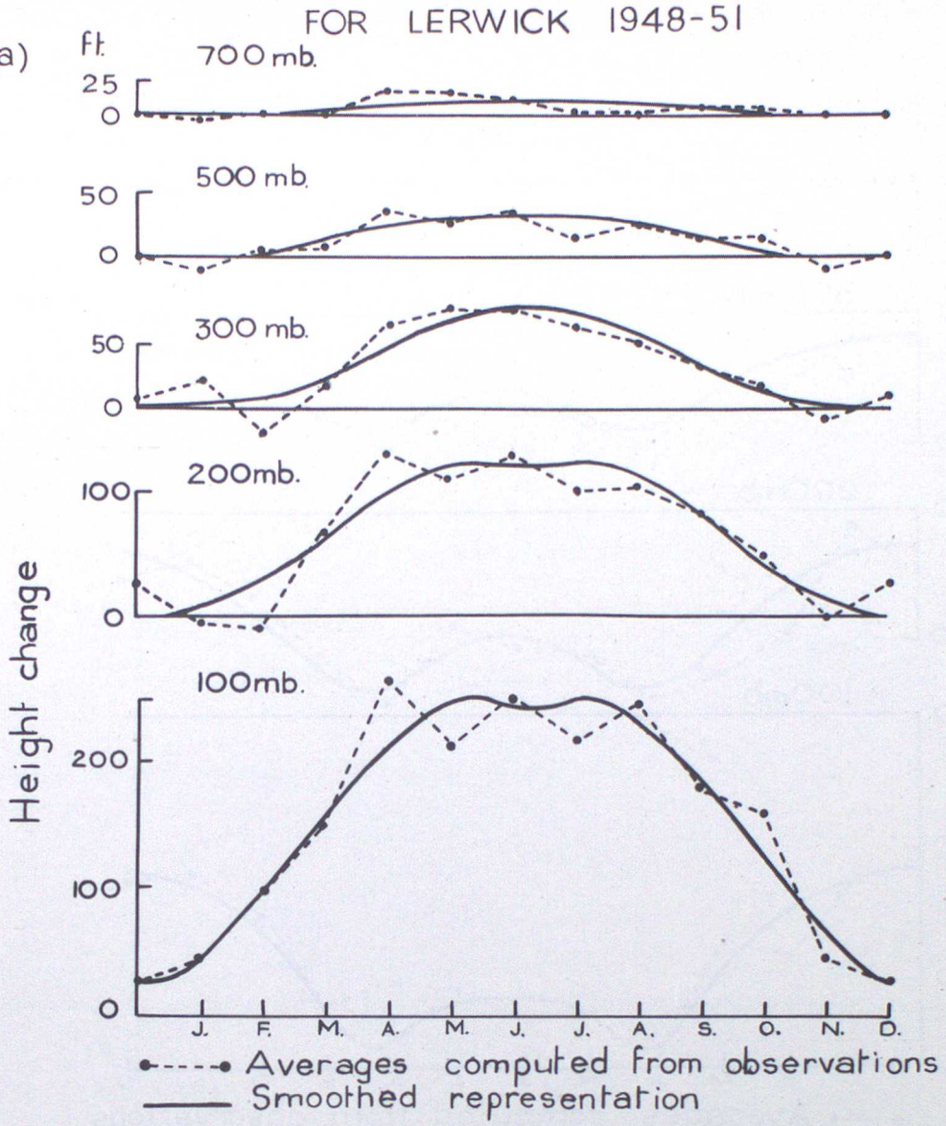
MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LARKHILL 1948-52

Fig 7(e)



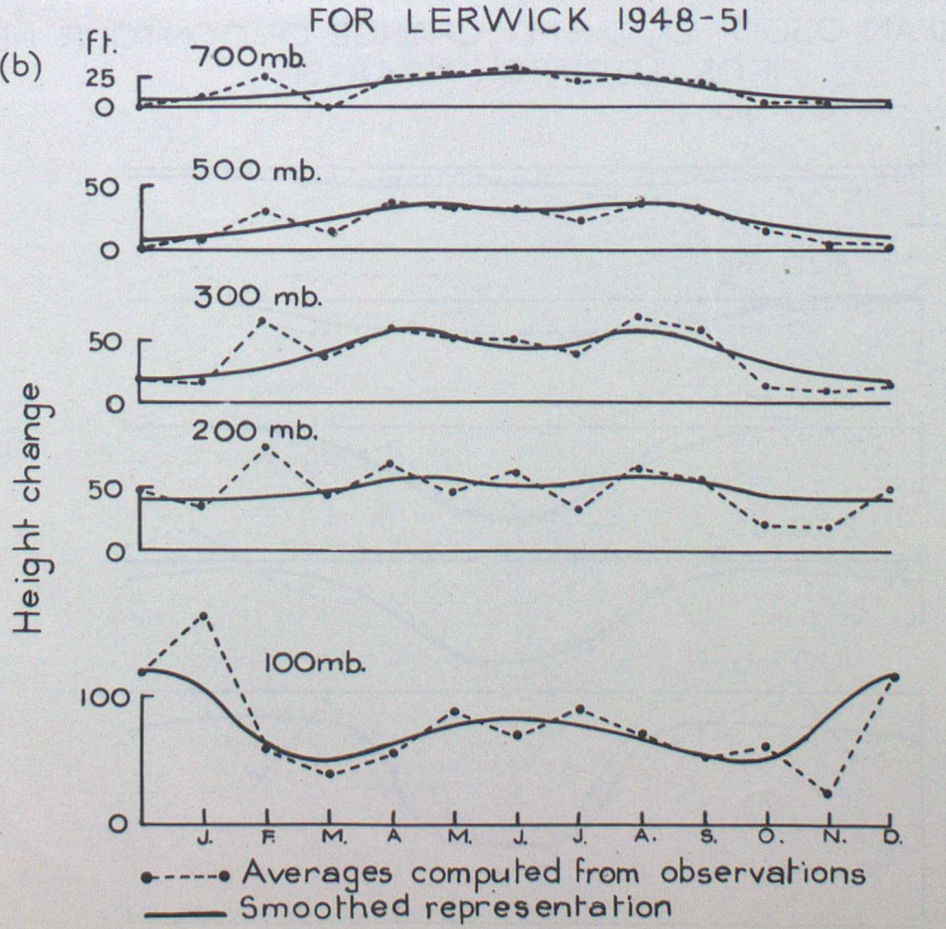
MONTHLY MEAN 0900-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 8(a)



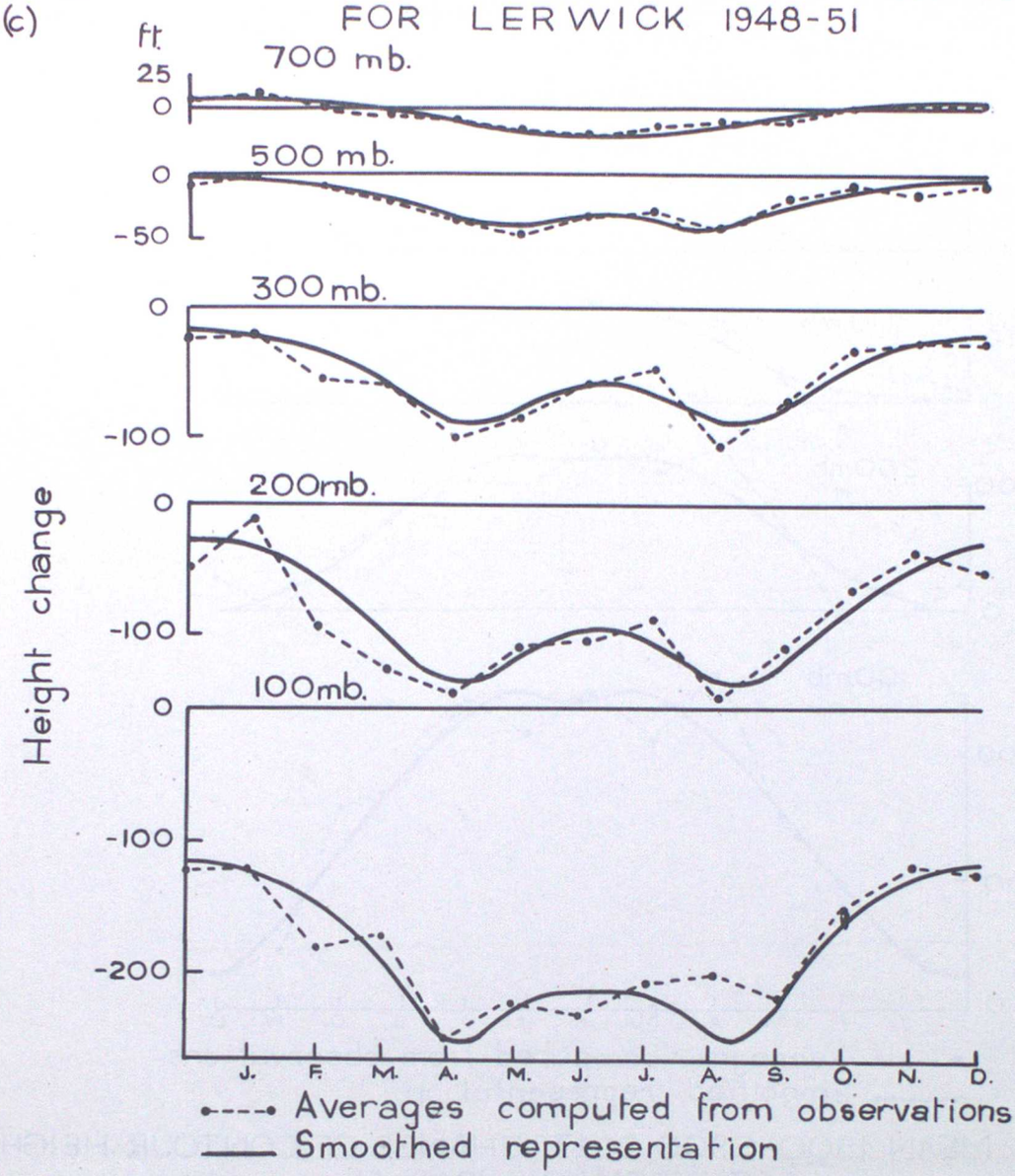
MONTHLY MEAN 1500-0900 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 8(b)



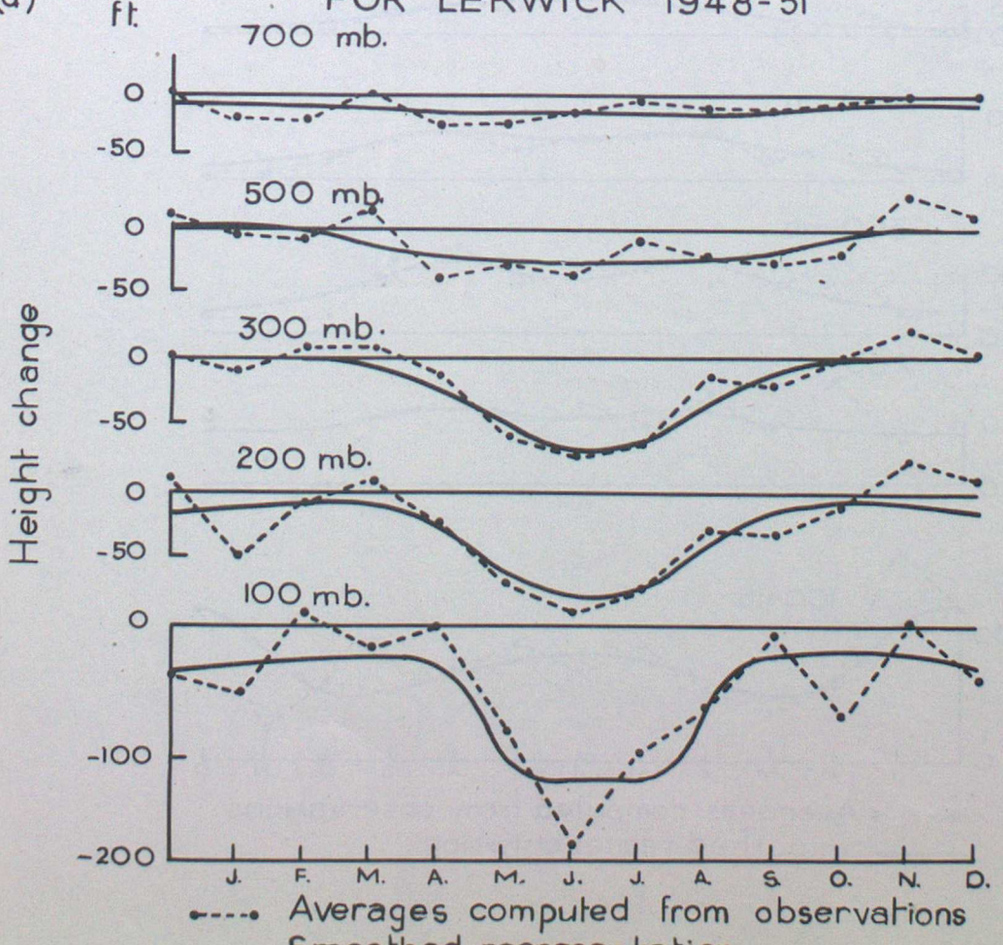
MONTHLY MEAN 2100-1500 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 8(c)



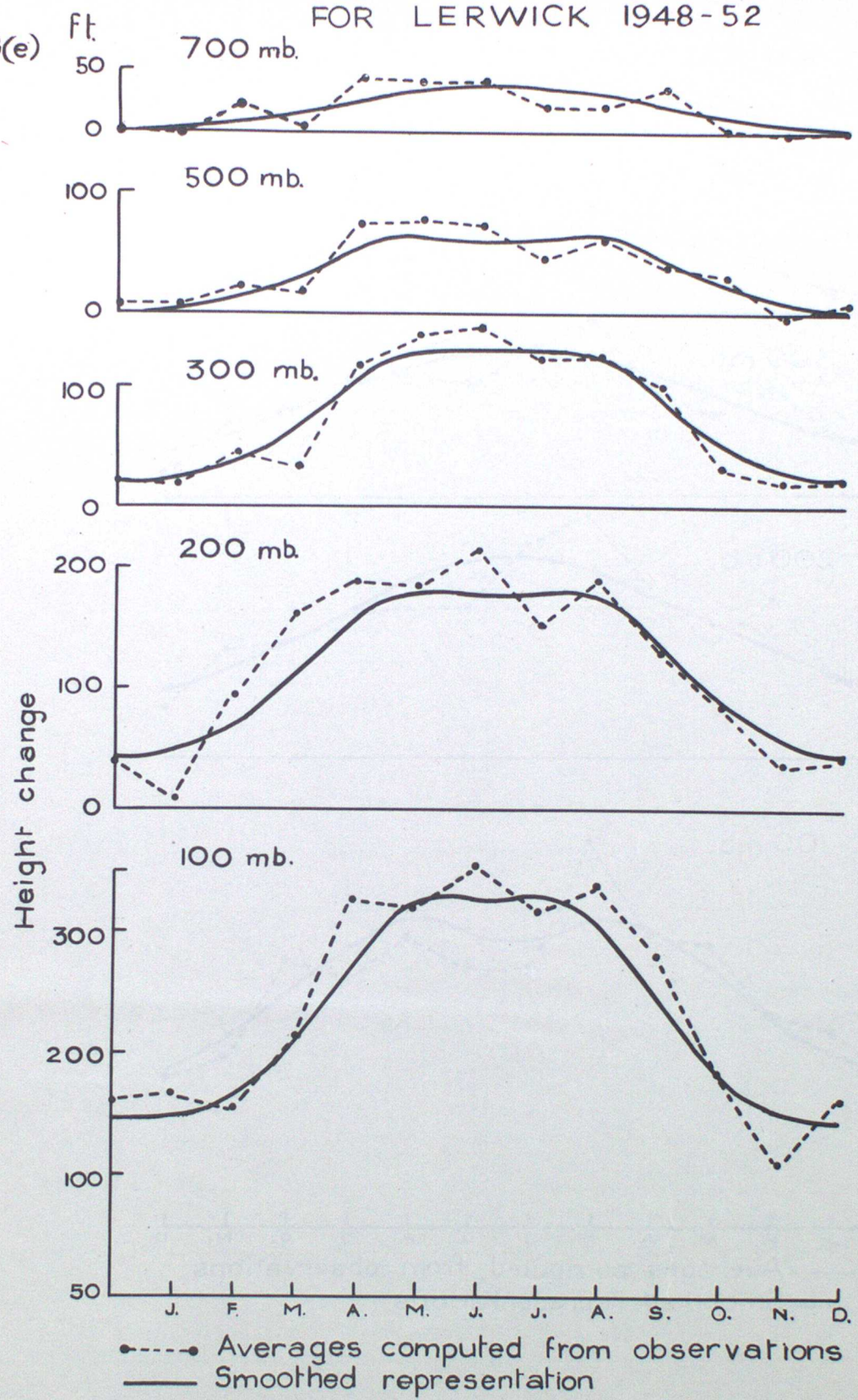
MONTHLY MEAN 0300-2100 G.M.T CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-51

Fig. 8(d)



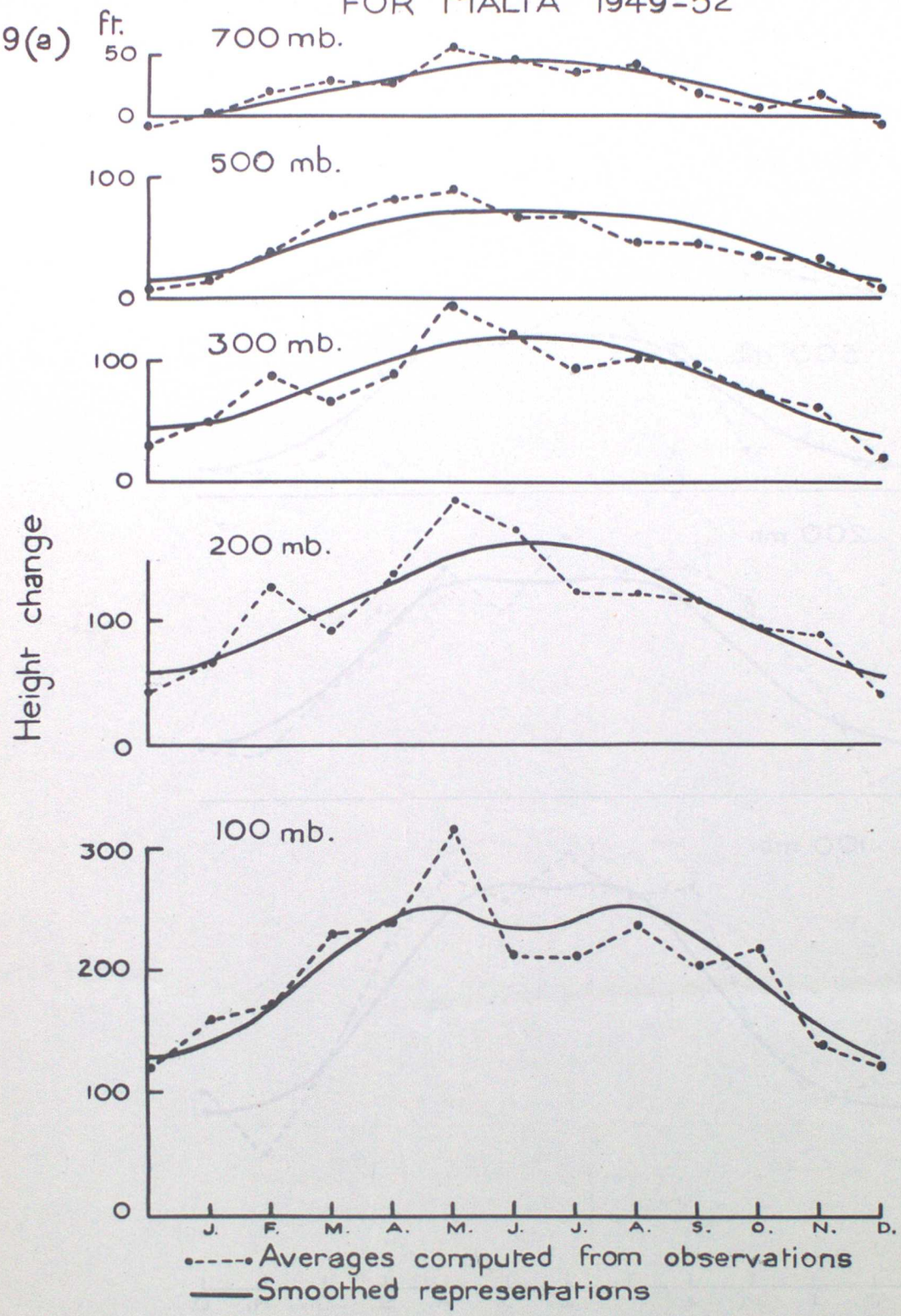
MONTHLY MEAN 1500 - 0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR LERWICK 1948-52

Fig. 8(e)



MONTHLY MEAN 1500-0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR MALTA 1949-52

Fig. 9(a)



MONTHLY MEAN 1500 - 0300 G.M.T. CHANGE OF CONTOUR HEIGHT FOR NICOSIA 1948-52

Fig.9(b)

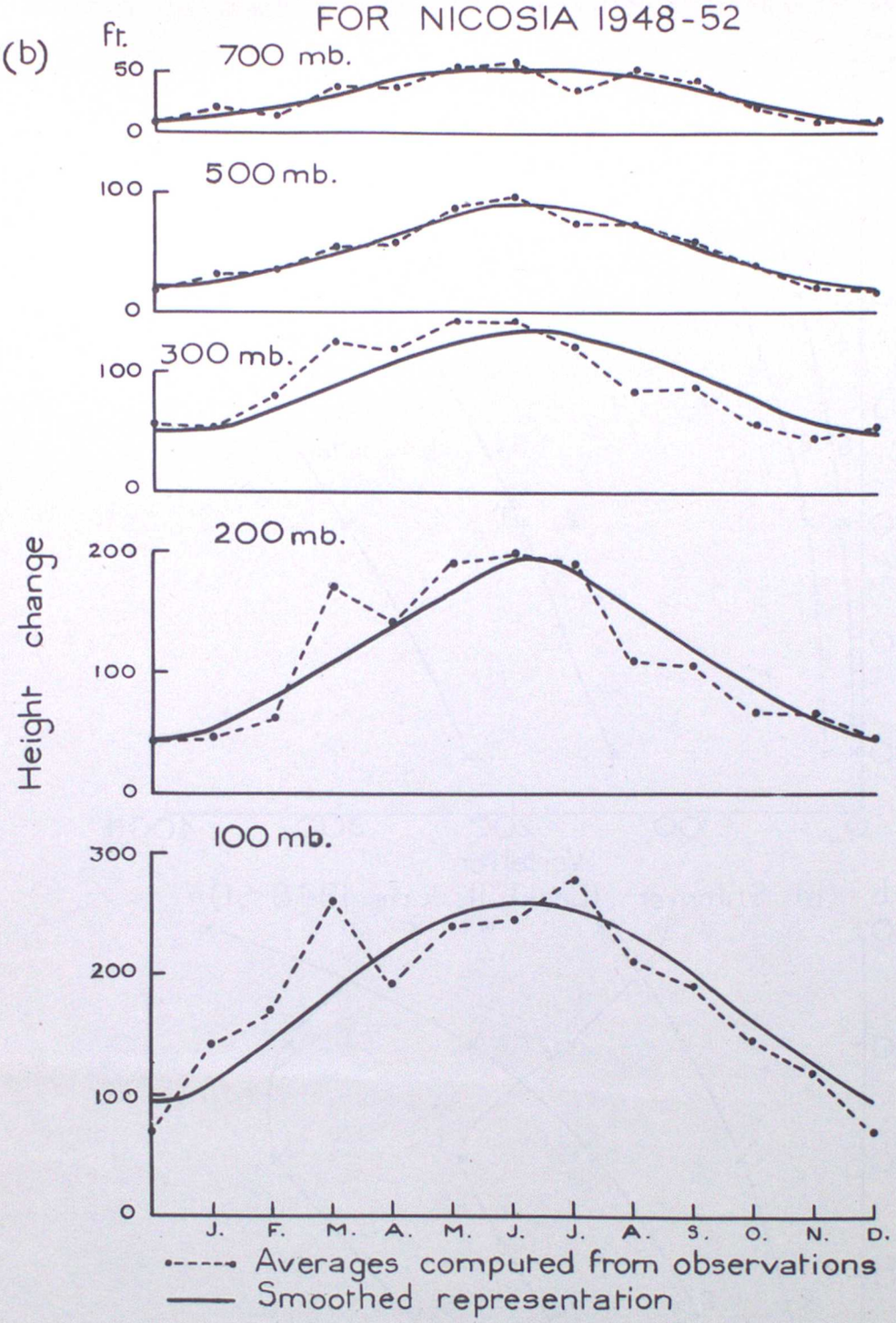
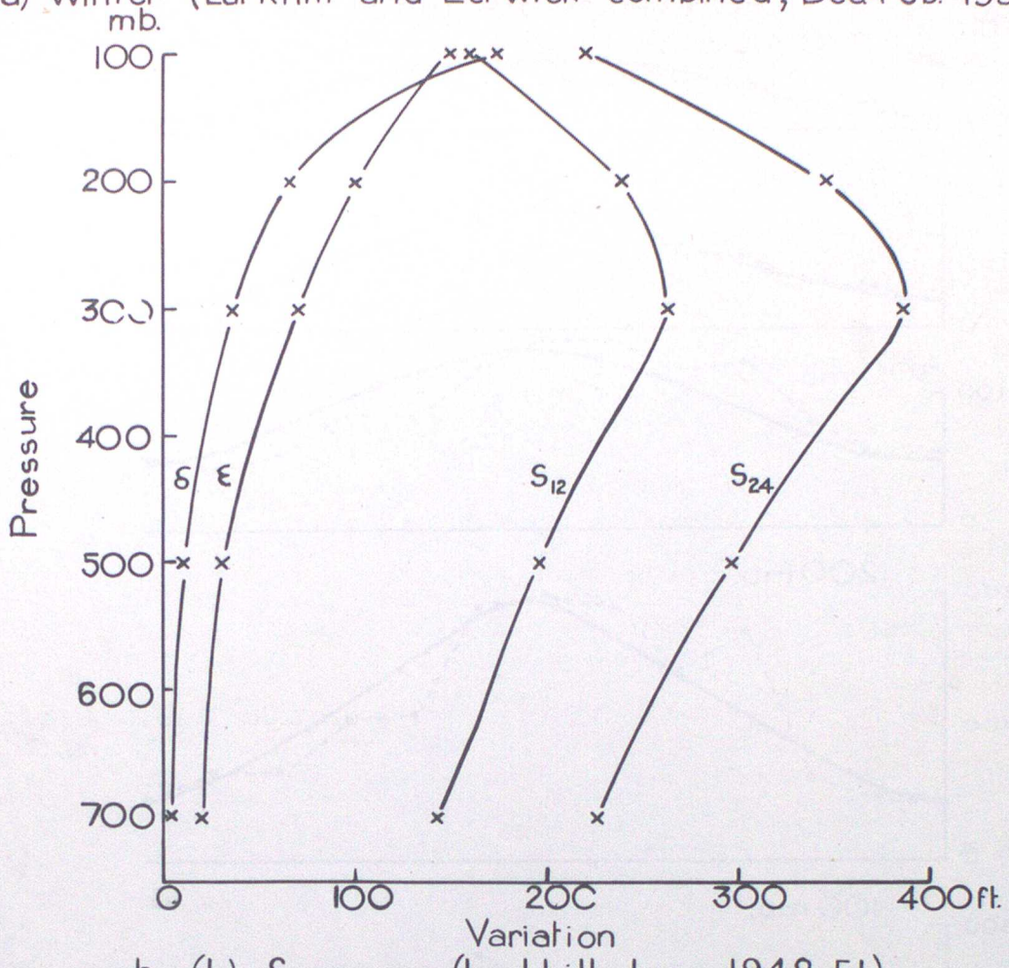
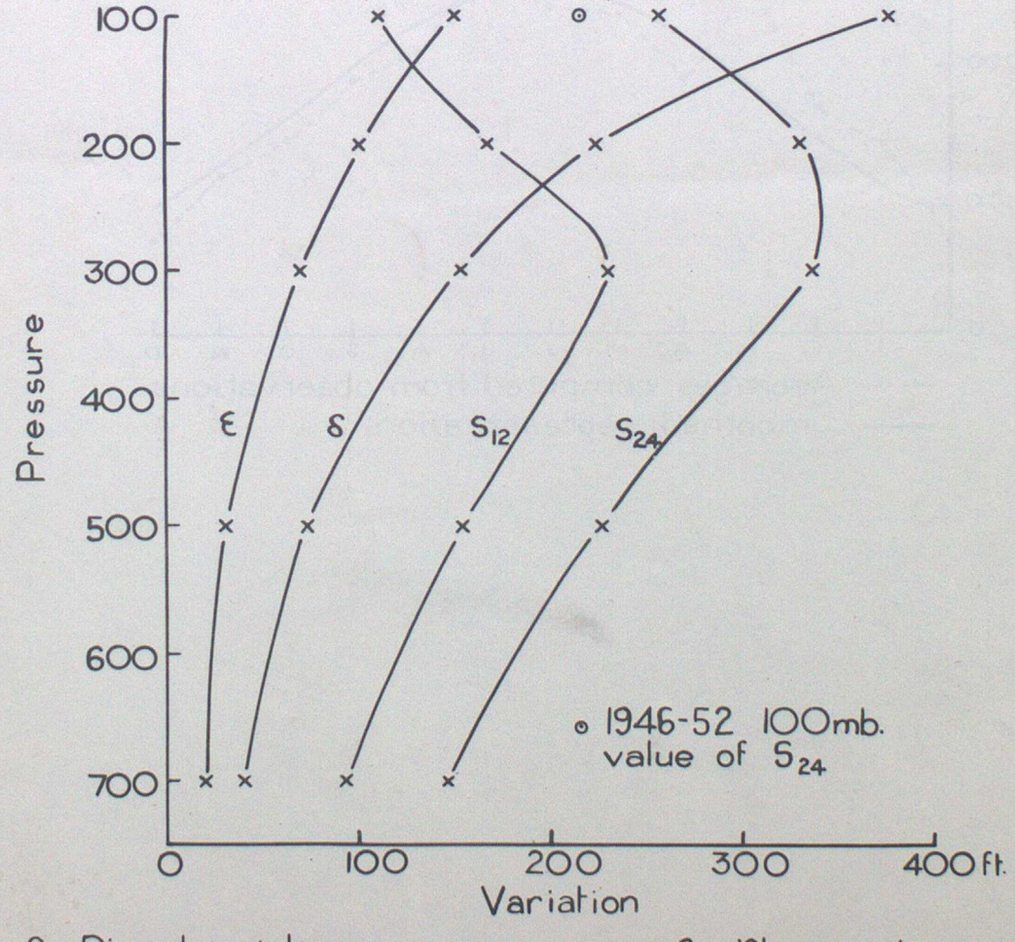


Fig.10 THE INTERDIURNAL VARIATION OF CONTOUR HEIGHT

(a) Winter (Larkhill and Lerwick combined, Dec-Feb. 1952-3)



(b) Summer (Larkhill, June 1948-51)



δ = Diurnal variation

ε = Standard error of measurement

S_{12} = 12hr. synoptic variation

S_{24} = 24hr. synoptic variation